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NOTES ON THE ORIGIN OF CLINTON HEMATITE ORES.

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THE generally accepted explanation of the origin of the Clinton hematite ores of New York and the Appalachians is that they were originally precipitated as ferric oxide or hydrate at the time that the associated sediments were deposited. The finding of Clinton ore composed of carbonate of iron in the deeper workings of the Irondale Mine, Wise County, Va., is, therefore, of considerable interest in determining the origin of the Clinton ores.

C. H. Smythe, Jr., in a report on the Clinton type of iron-ore deposits [2] states that he originally held the view that the Clinton ores might have resulted from different processes at different points in the Appalachians, but he finally concludes "that with few exceptions, all the Clinton ores must have had the same origin." The two main views as to the origin of the ores, which he presents, may be summarized as follows: The theory of the primary origin of the ore holds that the iron was brought in solution into shallow and perhaps inclosed basins and was there precipitated by oxidation, by reaction with the calcium carbonate of shells, or by the action of bacteria, algae, and other organisms. According to this theory the ore is an integral part of the

[1] Published with the permission of the Director, U. S. Geol. Survey, and Director, Virginia Geol. Survey.

[2] "Types of Ore Deposits," H. F. Bain and others, *Mining and Scientific Press*, 1911, pp. 33–52.

stratified series. This was generally held by our earlier geologists, but later the replacement hypothesis was urged and somewhat generally accepted. The replacement hypothesis holds that there was no marked concentration of iron in the Clinton rocks as originally deposited, but that secondary concentration was brought about by circulating ground water, which dissolved the diffused iron content of the sediments as bicarbonate, sulphate, or organic salts, which in turn was precipitated by coming in contact with limestone and replaced it. Mr. Smythe considers the evidence to favor the primary origin of the iron, but admits that a minor amount of secondary enrichment by ground water might have taken place. He states that such secondary ores would probably lack the essential characters of Clinton ores, and that no enriched Clinton ores have come to his notice. He states that the iron was probably deposited for the most part as limonite, with perhaps subsidiary iron carbonate. The dehydration of the limonite may have followed soon after precipitation, or it may have been a slower process, aided by pressure and slight temperature increase.

A modification of the hypothesis of primary deposition as above described has been advocated by S. W. McCallie,[3] whose view is that the iron was originally deposited as glauconite instead of limonite, based on the finding of green iron-silicate nuclei in some oölitic ore. These theories of origin as well as the occurrence of iron ore deposits in general are rather fully reviewed by E. C. Harder in his paper on iron depositing bacteria and their geologic relations.[4]

In the study of the geology of Wallen Ridge for the Wise County report of the Virginia Geological Survey, just published,[5] Clinton hematite ores mined in the vicinity of Irondale and Oreton were incidentally observed. The section of the Clinton formation in Wallen Ridge is as follows:

[3] "Fossil Iron Ore of Georgia," Geol. Survey of Georgia, Bull. 17, 1908, pp. 185–194.

[4] U. S. Geol. Survey, Prof. Paper 113, 1919, pp. 48–82.

[5] Va. Geol. Surv. Bull. XXIV., 1924.

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SECTION OF CLINTON FORMATION IN WALLEN RIDGE.

	Feet.
White quartzite in thick slabby beds	15
Thick-bedded dark-red sandstone	20
Gray to chocolate and pink shale, buff sandy shale, and thin granular sandstone, highly fossiliferous	180
Soft olive to drab platy shale and thin platy sandstone	20
Bed of fossiliferous hematite (Beb A)	2
Gray to brown shale with few thin sandstones	90
Oolitic to fine and coarse pebbly hematite interbedded with sandstone (Bed B)	2–4
Thick-bedded red and gray sandstone and shale	23
Thin bed of hard siliceous hematite	1–4
Shale with thin beds of fine-grained hard quartzitic sandstone, with a phosphatic and ferruginous conglomerate at base	45
	398–403

The most complete record of several bore holes near Oreton, at the east base of Wallen Ridge, shows the ore-bearing middle part of the formation to have the following composition:

RECORD OF BORE HOLE OF PROSPECT NO. 1, NEAR WILDCAT SUMMIT, ORETON.

(Condensed from record by Interstate Coal & Iron Co.)

	Thickness. Feet.	Depth of Base. Feet.
Gray and blue shale with few thin layers of sandstone	134	134
Calcareous shale with thin sandstone beds containing fossils	7	141
Shales and sandstone	37	178
Iron ore and sandstone interbedded. (Bed A.)	12	190
Brown shale with few thin sandstone beds	83	273
Iron ore and shale. (Bed B.)	6	279
Thick red sandstone	7	286
Sandstone and shale	14	300
Red sandstone and iron ore	3	303
Hard sandstone and shale		

The upper iron-ore bed (bed A) is generally a fine-grained fossiliferous hematite which encloses numerous crinoid-stem segments and fossil shells that have been replaced by iron oxide, closely similar to the fossil Clinton ore of Alabama and New York. The next lower bed (bed B) is generally composed of thin layers of oölitic to pebbly hematite, the matrix containing some fossils replaced by iron oxide, interbedded with thin layers of fine-grained

dense hematite ore. The pebbly beds contain some scattered large pebbles, up to 5 inches in longest dimension, which are mostly flat fragments of bedded material, now red hematite, containing molds and casts of fossils. These pebbles were evidently derived

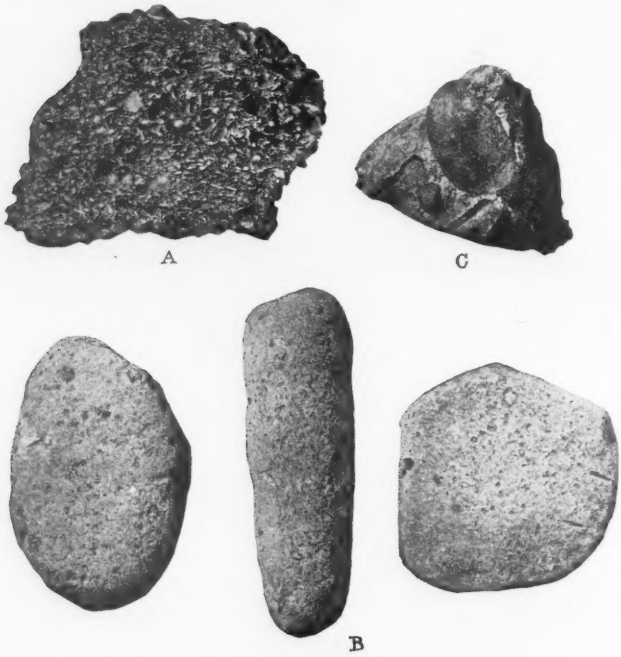

FIG. 46, *A*. Pebbly and oölitic hematite, from bed *B*, Irondale Mine, Wise County, Va. Small round pebbles of quartz coated with shiny reddish-black iron oxide, and oölitic grains of hematite, mostly with quartz centers, inclosed in a matrix of hematite.

FIG. 46, *B*. Pebbles of hematite, from bed *B*, Irondale Mine, Wise County, Va. Flat, bedded, fossiliferous material rounded and smoothed by wear, having a red shiny surface but dull reddish-gray within.

FIG. 46, *C*. Rounded pebbles of gray siderite inclosed with quartz pebbles in quartzose sandstone. From deeper workings on bed *B*, Irondale Mine, Wise County, Va.

from fossiliferous sedimentary beds, thin fragments of which were broken off and rounded by wear, for their surfaces, although finely pitted, are otherwise smooth and round. (See Fig. 46.) Fragments of soft material could not readily be transported and battered and their edges worn round without being reduced to small pebbles, and it seems more likely that when these large flat pebbles were thus formed they were composed of harder material than hematite, of which they now consist. That they were probably carbonate of iron is suggested by the ore in the deeper workings.

The workings had been abandoned several years and the tunnels could not be entered with safety. Some of them were reported to be ¼ mile long and the face was about 200 feet below the surface. Some of the ore brought from these deeper tunnel workings is a hard, gray, fossiliferous bedded sedimentary rock composed of almost pure carbonate of iron containing scattered grains and small pebbles of quartz. The fossils are also composed of carbonate of iron. This rock is so similar in structure to that of the large pebbles of hematite in the ore mined near the surface that it is believed to be the kind of material from which the pebbles were derived. There is also in the ore from the deeper workings a conglomerate of scattered gray, rounded, pebbles, composed of dense, nearly pure carbonate of iron, inclosed in quartz sand. These pebbles were evidently derived from concretions of carbonate of iron in the bedded rock. Part of the freshly deposited material was apparently temporarily exposed to erosion shortly after deposition and pebbles of the bedded carbonate rock and of the carbonate concretions were redeposited with rounded grains and pebbles of quartz, forming thin beds of conglomerate in sandstone. The flat pebbles are not assorted nor laid flat in the bed but lie at various angles in the conglomerate. (See Fig. 46.)

It appears therefore, that at the Irondale mine in Wise County, Va., the original ore is, at least in part, a sedimentary carbonate of iron containing quartz grains and pebbles of hard concretionary iron carbonate. No oölitic carbonate ore was observed

in the material from the deeper workings, but it is probable that the oölitic hematite ore was also originally carbonate of iron, deposited in concentric layers around quartz nuclei.

In the zone of circulating ground water, the carbonate ore is oxidized to hydrated ferric oxide by waters descending from the surface, and a part of the carbonate of iron goes into solution. That these ferruginous solutions penetrate the adjacent rock and tend to replace it is reasonable to expect, and various stages of such replacement have been observed in specimens obtained from the Irondale mine. The pebbly sandy layers are apparently the most porous beds and furnished free channels for the circulation

A B

FIG. 47, *A*. Banded hematite ore from bed *B*, Irondale Mine, Wise County, Va. Bands of oölitic to pebbly hematite separated by beds of dense fine-grained hematite, which has replaced sandstone.

FIG. 47, *B*. Oölitic to pebbly bed of hematite grading through dense fine-grained hematite into barren sandstone, from bed *B*, Irondale Mine, Wise County, Va. The cross-bedded wedge of barren sandstone lies between two layers of pebbly oölitic ore, the lower one forming the bottom of the specimen. The sandstone adjacent to the pebbly layer is replaced by dense hematite, which grades through partly replaced sandstone into the barren sandstone.

of water. The sandstone immediately adjacent to the pebbly layers is generally completely replaced by hematite, forming a

solid layer of dense structureless hematite ore. This dense ore grades away from the source of the iron solutions first into ore containing scattered quartz grains, then into ferruginous sandstone, then into iron-stained sandstone, and ultimately into unaltered sandstone farthest from the pebbly layer. The completely enriched zone consists of alternate layers of dense hematite and fine pebbly hematite. (See Fig. 47.)

The conclusion is therefore reached that the hematite ore in the Clinton formation at the Irondale mine was, at least in part, originally deposited as carbonate of iron; the iron carbonate was changed to hydrated ferric oxide in the zone of ground water and later, through heat and pressure, became hematite; the adjacent sandstone was replaced to a greater or less extent by hematite, the replacement in places converting the barren or lean rock into a dense hematite. The present form and richness of the ore at the surface is therefore believed to be due largely to the oxidation of thin layers of carbonate ore and to the replacement of interbedded sandstone by iron oxide.

The finding of carbonate ore at depth at one mine is insufficient evidence from which to draw sweeping conclusions. There seems to be no reason to doubt that most Clinton hematite ores were originally deposited as ferric oxide, but the Virginia occurrence of carbonate ores seems to be one of the exceptional cases, mentioned as possible by Mr. Smythe, where the iron was deposited as a carbonate. Further study, however, in other regions may establish the fact that this mode of deposition was not restricted to the deposits at Irondale.

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TYPES OF MAGNESITE DEPOSITS AND THEIR ORIGIN.†

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INTRODUCTION.

MAGNESITE from different types of deposits and of different degrees of purity has different uses. The purchaser of refractory brick requires a low lime grade and prefers the material carrying some iron because he has found it most suitable. The purchaser

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* For help in preparing this paper, the writer is greatly indebted to Prof. James F. Kemp for advice, helpful criticism, and assistance in arranging the subject matter in its present form.

of crude magnesite for the manufacture of CO_2 is not so rigorous in his requirements, and in South Africa high lime magnesite has been used for this purpose. It is only fitting, therefore, that an outline of the properties, preparation and uses of magnesite should precede an account of the occurrences and economic importance of the mineral deposits.

PROPERTIES, PREPARATION AND USES OF MAGNESITE.

Chemically magnesite is less active than calcite or dolomite. It is not decomposed by cold concentrated hydrochloric and sulphuric acids but effervesces freely when the acids are heated. Magnesite gives up its CO_2 at a temperature below 600° C.,[1] while calcite retains its CO_2 at temperatures up to 875° C. The magnesia produced by calcining the carbonate is very refractory, having a melting point at about 2500° C.,[2] but this point is lowered by even small percentages of lime. Unlike lime, magnesia does not combine so readily with silica to form silicates; it is further unlike lime in that when it is dead burned it will not take up water or CO_2 [3] to form hydroxides and carbonates. Thus magnesia, as the calcined product is called, is relatively inert; it is hard and massive, retains the rhombohedral cleavage and is readily distinguished from dolomite by its pinkish tint while dolomite remains white.

Magnesite is marketed in four forms: 1. Crude magnesite. 2. Caustic calcined. 3. Dead burned. 4. Clinker.

The chief use of high grade, dead burned, magnesite is as a refractory material in the metallurgical industries. Its high melting point and relative chemical inertness render it particularly suited for this purpose. Magnesite is also used in the manufacture of oxychloride or Sorel cement. As a flooring material, Sorel cement is superior to ordinary cement in that it

[1] K. Grunberg, "Beitrag zur Kenntis der naturlichen kristallistierten Karbonate des Calcium, Magnesiums, Eisens und Mangans," *Zeitschrift fur Anorg. Chem.*, vol. 80, p. 337.

[2] M. Goodwin, *Jour. Amer. Electro. Chem. Soc.*, vol. 9, p. 89.

[3] R. H. Youngman, *Met. and Chem. Eng.*, vol. 12, p. 620; Imperial Mineral Resources Bureau, Bull. 19, 1920.

has a very low coefficient of expansion and will take a high polish. The cement is made of a mixture of finely powdered magnesite and magnesium chloride; when wet with a solution of magnesium chloride it sets and forms a hard vitreous mass. Magnesite gives up its CO_2 at a lower temperature than the other common carbonates and for this reason has been used in the manufacture of carbon dioxide gas.

Other uses of the material depend upon the magnesium content of the mineral rather than upon its physical properties. Some of the more important uses are magnesium bisulphide used in the manufacture of pulp and paper, metallic magnesium, magnesium chloride, cold water paint and several other products of the chemical industry. In addition it is used along with other materials in the manufacture of medicinal and toilet sundries. These take a very small percentage of the output and require freedom from certain impurities which are not so objectionable in material for the metallurgical industries.

TYPES OF MAGNESITE DEPOSITS.

Up to the present time four main types have been described:

1. Magnesite as a sedimentary rock.
2. Magnesite as an alteration of serpentine.
3. Magnesite as a vein filling.
4. Magnesite as a replacement of limestone and dolomite.

Although deposits have been recognized and described it is hard to find in the literature any correlation between mode of origin, and chemical composition, local distribution and properties of material from the different types; this paper attempts to set forth these correlations in a comprehensible manner.

Magnesite as a Sedimentary Rock—Type I.

Carbonate of magnesia occurs as a sedimentary rock at Atlin, B. C., and in Kern Co., California.

Atlin, B. C.[4]—The deposit lies in a basin and is about six to

[4] G. A. Young, Summary Rept. C. G. S., 1915.

eight feet thick over an area of eighteen acres. The material is not magnesite, but hydromagnesite in a white powdery form.

The following are the results[5] of the slightly impure material as sampled:

SiO_2	1.86	0.90	0.54
Al_2O_3	0.67	0.10	0.17
Fe_2O_3	0.15	0.09	0.11
FeO	0.60	0.45	0.64
CaO	2.04	0.82	0.68
MgO	41.13	42.35	42.19
CO_2	35.98	36.10	36.17
H_2O	18.02	18.95	19.05
H_2O (Subt.)	1.92	1.61	1.35
	100.45	99.76	99.55

The deposits have not the tuffaceous character of spring deposits nor do they lie on top of ferromagnesian rocks from which they could have derived their magnesia. They probably represent a lake deposit which has become exposed owing to the drying up of the water.

Kern Co., California.[6]—The deposits are situated in the Mohave Desert of Central California. Outcrops are few and the geology has been worked out from exposures in prospecting pits and on ridges of hard limestone which resist erosion.

The mineral bodies show a distinct bedded structure, and are interstratified with clays and clay shales forming a member of a series of cherty limestones which outcrop in ledges nearby. The magnesite beds and interstratified clay seams are soft, so that outcrops are rare. The strata are variable and consist of alternating layers of clay and magnesite in beds up to 1′ 6″ thick, but usually much less. The total thickness of the magnesite-bearing portion is from six to ten feet. The strata are badly distorted and lenticular in the thicker parts. Slip planes are rather common and when these occur the bedding becomes rather indistinct.

The magnesite is fine grained and breaks with a conchoidal

[5] *Idem.*

[6] H. S. Gale, Bull. 540, U. S. G. S., pp. 512–516.

fracture. On exposure to the atmosphere and rain it crumbles to an earthy powder. The composition [7] is given by the following analyses:

SiO_2	9.64	8.51	6.03	4.75
$Al_2O_3 + Fe_2O_3$	2.46	2.94	1.40	0.76
CaO	4.25	3.36	1.56	Tr.
MgO	37.19	38.32	42.78	44.20
CO_2	40.70	40.12	45.78	47.32
Undet.	5.76	6.75	2.45	2.97

When the mineral composition is calculated from these analyses it is found that there is insufficient CO_2 to combine with the MgO to form $MgCO_3$. Evidently some of the magnesia is present as $Mg(OH)_2$ in the hydromagnesite molecule $MgCO_3 \cdot Mg(OH)_2$. Thus to a limited extent the deposit has the same mineral composition as that occuring at Atlin, B. C.

Chemistry of Deposits.—The lime content at Atlin and in Kern Co. is remarkably low for sediments, unless sedimentation took place under extraordinary conditions. The shale and magnesite beds have the variable characteristics of lake deposits and point to the formation of the magnesite by a chemical precipitation and subsequent dehydration during the dynamic metamorphism of the beds.

The lakes in which the precipitation took place are supposed to have been filled with brines rich in sodium carbonate and other soluble salts. Spring waters rich in magnesium salts, possibly magnesium sulphate, flowed into the lake; reaction took place between the sodium carbonate of the brines and the magnesium sulphate of the springs to produce relatively insoluble hydromagnesite and soluble sodium sulphate. Since calcium carbonate, calcium sulphate, sodium carbonate and sodium sulphate are many times more soluble than magnesium carbonate, they would remain in solution, allowing a relatively pure precipitate of magnesium carbonate to form. Sedimentation of a later date has buried the deposits and preserved them from erosion.

[7] *Idem.*, p. 514.

Magnesite as an Alteration of Serpentine—Type II.

Magnesite derived from serpentine rocks occurs in several countries and widely separated areas. The magnesium carbonate of these deposits is exceedingly fine grained, having the appearance of unglazed porcelain; it has a conchoidal fracture, a specific gravity above three and a hardness of five.

The mineral occurs in veins cutting serpentines from which the magnesia is evidently derived by the decomposition of the silicate in the presence of water carrying an excess of CO_2. The chemical reaction taking place on its formation is usually expressed as follows:

$$H_4M_3Si_2O_9 + 3CO_2 = 3MgCO_3 + 2H_2O + 2SiO_2$$

The magnesium carbonate is deposited in veins and the silica carried away in solution; some slight amount of silica is deposited as opal.

The chief deposits of this type are in Eubea, Greece, and in California. Deposits of lesser importance are found in Victoria, Australia;[8] Mysore and Salem, India;[8] Transvaal, South Africa;[8] and Maryland, U. S. A.

Eubea, Greece.[9]—The Grecian magnesite quarries are situated on the Island of Eubea which lies in the western part of the Ægean Sea and is separated from the mainland by the Canal d'Atlanti.

A belt of peridotite rocks, of Jurassic age, and largely altered to serpentine stretches across the island from east to west. The magnesite occurs in shear and fracture zones in both the peridotites and serpentines, pointing to a double decomposition of the olivine according to the following action:

$$H_2O + 2Mg_2SiO_4 + CO_2 = H_4Mg_3Si_2O_9 + MgCO_3,$$
$$H_4Mg_3Si_2O_9 + 3CO_2 = 2H_2O + 2SiO_2 + 3MgCO_3.$$

In places the magnesite veins become so numerous that they con-

[8] Bull. No. 19, Imperial Mineral Resources Bureau, 1920.

[9] H. C. Boydell, Economic Geology, Vol. XVI., pp. 507–523, 1921.

stitute a magnesite rock with but a few remnants of serpentine to show the original structure. Two processes have been at work:

1. Solution of the silica and serpentine.
2. Concentration of the magnesite in veins and stockworks.

The deposits attain a depth of over 300 feet and cover a large area. The maximum annual production was 150,000 tons for 1914. Analyses[10] of the material mined gave the following composition:

SiO_2	0.86	1.54
$Al_2O_3+Fe_2O_3$	0.55	0.33
CaO	0.55	1.21
MgO	46.94	46.38
Ignition	51.10	49.84
Moisture		0.70

California, U. S. A.[11]—The magnesite of California resembles that of Eubea in texture, and its mode of occurrence and origin seem to be similar. The mineral occurs in serpentinized rocks derived from peridotites and pyroxenites which underly about 1000 square miles in the Coast Range Mts. of California. The peridotites belong to a series of batholithic intrusives of Cretaceous age which since consolidation have been greatly faulted and broken up. Solutions carrying CO_2 have penetrated along these fractures and decomposed the enstatite and olivine, with the formation first of serpentine and later magnesite. The silica was carried away and the magnesium carbonate deposited in the space formerly occupied by the serpentine; since the carbonate occupied only four-fifths of the volume of the serpentine, considerable shrinkage and additional fracturing must have taken place enabling the carbonated waters to carry out their work more completely. Serpentine in all stages of decomposition is found in the brecciated zones and veins.

A number of typical analyses are given below:

[10] *Idem.*, p. 522.

[11] F. L. Hess, Bull. 355, U. S. G. S. H. S. Gale, Bull. 540, U. S. G. S.

SiO_2	0.41[12]	0.51[13]	0.23[14]
Al_2O_3	0.28	1.98	0.04
Fe_2O_3	0.12	0.16	0.20
CaO	0.03	0.59	0.19
MgO	47.16	45.84	46.88
CO_2	51.88	50.80	51.57
	99.88	99.88	99.11

In 1915 the mines produced 30,500 tons of crude magnesite, having a value of $274,500.

Chemistry of Deposits.—The origin of the carbonated waters essential to the formation of this type of deposit is still a debatable question. Workers have shown that some of the deposits in the serpentines were formed by ascending thermal waters given off by the consolidation of the deeper portions of the same magma, while others think that meteoric waters have brought about the change. The nature of the alteration, notably the lack of oxidized products and the intense penetrating power of the solutions effecting the alteration, favors the view of attack by magmatic waters and if such is the case, the deposits can be expected to go down to great depths rather than being merely superficial, in fact those which have been explored most thoroughly go below the zone of oxidation and seemingly below the zone of supergene solutions. In either case, alteration and replacement of the serpentine and transportation of magnesite and silica have played an important part, the silica has been held in solution probably as soluble silicic acid and the magnesite has been precipitated as soon as the decrease in pressure would allow the excess CO_2 to escape, thus giving a product relatively free from impurities.

Magnesite as a Vein Filling—Type III.

Magnesite as a vein filling is relatively unimportant from an economic point of view. The several deposits usually described as belonging to this class are not all veins, but include many oc-

[12] F. L. Hess, *op. cit.*, p. 21.
[13] *Idem.*, p. 23.
[14] *Idem.*, p. 24.

currences forming a connecting link between the fissure veins proper and the replacement deposits.

Near West Beach, New Brunswick,[15] magnesite occurs as a vein cutting a gray chloritic schist.

Sir Wm. Logan describes an occurrence of magnesite in Bolton and Sutton Townships,[16] Quebec. At Bolton the magnesite forms a deposit lying between steatite on one side and serpentine on the other. The deposit closely resembles crystalline limestones and contains in addition to magnesite, the minerals dolomite, nickeliferous pyrrhotite, and a nickeliferous silicate. Analyses[17] gave the following:

Insoluble	8.03	45.90
$FeCO_3$	9.02	19.35
$CaCO_3$	0.00	0.00
$MgCO_3$	83.33	33.00
Al_2O_3		0.50
	100.40	98.70

In Sutton Township the magnesite forms a vein about a foot thick and lies between gray micaceous schists.

At Lac des Mille Lacs, Algoma, Ontaria,[18] a blue ferruginous magnesite occurs in association with pyrite.

Magnesite as a vein filling has been reported from several localities in British Columbia[19] and the Yukon,[20] but published accounts of these occurrences are usually lacking in detail.

In all cases the magnesite is highly ferruginous and merely represents an over-concentration of a single mineral in the ordinary type of fissure vein formed by precipitation from rising juvenile waters.

[15] L. W. Bailey and G. F. Matthews, Rept. of Progress, C. G. S., 1870–71, p. 237.

[16] W. Logan, "Geology of Canada," 1863, pp. 457–458.

[17] *Idem.*, p. 457.

[18] Annual Rept. C. G. S. 1885, Pt. M., p. 22.

[19] Annual Rept. C. G. S. 1895, Pt. S., p. 96.

[20] Annual Rept. C. G. S. 1898, Pt. R., pp. 15–16.

Magnesite as a Replacement of Limestone—Type IV.

The most important deposits known, namely those at Veitsch, are of the replacement type. Similar but smaller occurrences are found in Stevens Co., Washington, and in Argenteuil Co., Quebec. An occurrence on Cape Breton Island also seems to be of this type. The magnesium carbonate is coarsely crystalline, white in appearance and usually has associated with it pale yellow or green serpentine. The magnesite occurs as a replacement of limestone through the agency of magnesia-bearing solutions of magmatic origin.

Geologists who have worked and studied the Austrian deposits for half a century have come to believe that the ore bodies were formed by the replacement of Carboniferous limestone through the agency of magnesia-bearing solutions. There is, however, some difference of opinion as to whether these solutions emanated from a silicic or a femic intrusive, both of which occur in close association with the magnesite deposits. At present similar doubt exists regarding the deposits in Quebec and Washington.

Styria, Austria.—As early as 1873 J. Rumpf [21] studied the magnesite rocks in the Austrian Alps and stated that the deposits seemed to be marine sediments, of Silurian age, and were deposited from saturated solutions of magnesium carbonate in warm waters. Later, in 1893, Kock [22] recognized fossils characteristic of the Carboniferous period and definitely expressed the opinion that the deposits were of contact metamorphic origin, but mistook the sediments which were not magnesite for limestone, whereas they are really dolomite.

In 1900 Weinschenk [23] mentioned the stock-like masses of magnesite in Liesing and pointed out their close relationship to the extensive talcose rocks of the region. Such formations he explained by the bringing in of pure magnesian compounds, as otherwise the dolomite stage would hardly have been passed. The pinolites Weinschenk believes are impregnations of the

[21] J. Rumpf, *Tschermaks Mineralogische Mtt.*, p. 263, 1873.
[22] M. Kock, *Zeitsch. Dtsch. Ges.*, p. 294, 1893.
[23] E. Weinschenk, *Zeitsch. fur Pract. Geol.*, p. 41, 1900.

"Tonschieffer" in which the most of the rock consists of flat rhombohedra of magnesite and the original Tonschieffer completely recrystallized.

In 1903 Kock and Redlich [24] showed that the magnesite was formed by the replacement of limestone and that in this respect it was analogous to the deposits of ankerite and siderite in the same district. In 1905 Weinschenk [25] explained the formation of the magnesite as due to the metasomatic replacement of limestone, the change being brought about by magnesia solutions emanating from granite laccoliths intruding the Carboniferous strata. In 1907 [26] Redlich showed that the limestone was first changed to dolomite and later to magnesite, but was inclined to regard basic intrusives as having supplied the magnesia.

Stevens Co., Washington, U. S. A.[27]—The magnesite deposits of Stevens Co. are situated in Chewelah Valley, fifty miles north of Spokane, Washington.

The magnesite is of the crystalline variety and occurs together with dolomite in beds of Carboniferous age. In most localities the limestones are dolomitic, but only near dikes do they approach magnesite in composition. The dikes are composed of dark green hornblende which is largely altered to chlorite and serpentine. The feldspar is also highly changed and magnetite surrounds grains of pyrite from which it is probably derived. In the hand specimen the dikes appear quite fresh and dark green in color. The alteration which has taken place is believed to be hydrothermal.

Near the dikes the limestone is much distorted and contains a yellowish green pseudoserpentine, sometimes identified as ophicalcite. At no point does magnesite occur in contact with the dikes, but rather just beyond this serpentine zone. Since the dikes show alteration similar to the limestone, it is thought that the change from limestone to magnesite took place long after their intrusion, and that the waters effecting the alteration were directly affected by the presence of the dike.

[24] K. A. Redlich, *Jahrbuch, d. Geol. Reichsanstalt*, p. 285, 1903.

[25] E. Weinschenk, *Grundzuge der Gesteinkunde-Frieburg*, Band II., p. 315.

[26] K. A. Redlich, *Tschermaks Mineralogische Mitt.*, p. 499, 1907.

[27] O. P. Jenkins, ECONOMIC GEOLOGY, vol. VIII., pp. 381–384, 1918.

All the deposits occur in a zone which intersects a series of plunging folds and this zone lies between a number of outcrops of a dike or dikes and the nose of the folds.[28] Evidently the workable deposits of magnesite all occur farther down the plunge of the folds than the intersecting dikes and more especially where the "inverted trough" structure is such as to concentrate any solutions which might be rising from great depths.

Argenteuil Co., Quebec.—The magnesite deposits of Argenteuil Co. are situated about eight miles north of the town of Grenville on the north shore of the Ottawa River between Montreal and Ottawa.

The deposits are of early pre-Cambrian age and occur in a metamorphosed group of sediments known as the Grenville Series. Associated with the magnesite are dolomite, garnet gneiss, biotite gneiss, feldspathic gneisses and serpentine. The serpentine occurs in the limestone as scattered grains or as large lenticles. The magnesite was formed by the replacement of the limestone through the agency of magnesia rich solutions which Wilson[29] believes came from a series of basic peridotite and pyroxenite dikes which are found cutting the limestones. More recently Bain[30] pointed out that the peridotite and pyroxenite dikes bear the same relations to the magnesite deposits as the more silicic intrusives in the Washington occurrence. Batholithic intrusives of Laurentian age break through the Grenville Series and basic dikes but are cut by the Keweenawan diabase. These later intrusives bear no relations whatever to the occurrence of the mineral deposits which, therefore, must have been formed in the interval between the intrusion of these later dikes and the earlier peridotites and pyroxenites.

The structure in the vicinity of the quarries indicated that all the magnesite or magnesite dolomite occurred on the crests of anticlines or below basic dikes; furthermore, the best material was obtained where the two structures were complementary. Such structures precluded the possibility of descending waters

[28] G. W. Bain—Unpublished Master's Thesis, McGill University.

[29] M. E. Wilson, Memoir 98, C. G. S., pp. 62–63.

[30] G. W. Bain, Bull. 1244 M., Amer. Inst. Min. Met. Engs., 1923.

having effected the concentration from dolomitic sediments. It was also shown that in these localities the original Grenville limestone was not dolomitic and that practically all the magnesia must have been introduced. Also the Laurentian magma was continually discharging in its emanations, magnesium silicate solutions [31] in excess of that required to produce the silication in the contact zones surrounding the limestone, dolomite and magnesite.

Typical analyses [32] of Grenville magnesite contain:

Insoluble	0.50	2.90	0.88
$CaCO_3$	15.60	12.20	14.21
$MgCO_3$	84.18	84.60	84.90
CaO	8.77	6.83	7.96

The magnesite grades into a more dolomitic variety which in turn passes into a dolomite and then into a crystalline limestone. In this type of deposit the grade of material, that is, the $MgCO_3$ content, is determined by the specifications of the buyers so that this feature and not silicate wall rocks marks the limits of the mineral deposits.

The Chemistry of the Replacement Deposits.[33]—When the magnesia was precipitated in fissures or near them, that is, under conditions unfavorable towards the reaction with limestone, silicates such as diopside, forsterite, chondrodite, talc and serpentine, were formed; the anhydrous magnesium silicates usually, although not always, occur in the crystalline limestones themselves, while the hydrous varieties are confined to the veins.

The forsterite, diopside and chondrodite were originally precipitated in crystal form and subsequently altered to serpentine and magnesite, but the major portion of the reaction seems to have taken place before precipitation. The evidence for the formation of primary serpentine is not so definite as for talc, which occurs in veins up to three quarters of an inch wide. In the veins the talc is arranged as flakes which usually extend from wall to wall. (Flaky talc in schists is developed so that the elon-

[31] G. W. Bain, *Jour. of Geol.*, vol. XXXI., pp. 657–666, 1923.

[32] M. E. Wilson, Memoir, 28, C. G. S., p. 41.

[33] G. W. Bain, Unpublished Master's Thesis, McGill University.

gation of the flakes is at right angles to the pressure.) In open fissures this type of pressure could only be exerted at right angles to the walls or in such a direction as would tend to close the opening. If dynamic pressure could be exerted at right angles to the talc flakes, prominent slickensiding and bending of the flake would be produced; such structures were not observed in any case. The absence of pseudomorphs of talc after diopside, forsterite or chondrodite, combined with the above structural features, seem to indicate that the talc is a primary vein-forming mineral.

An analogous behavior on the part of a vein of serpentine seems to point to a similar primary occurrence of that mineral. Evidently secondary serpentine does occur and then it is quite clearly a hydrothermal decomposition product of diopside, forsterite and chondrodite.

The solutions carrying talc, serpentine, diopside, forsterite, and chondrodite either as dissolved mineral matter or as simple solutions reacted with the limestone to set free CO_2 which immediately attacked the unstable magnesian minerals and solutions in the same manner it would a crystallized peridotite, the only difference being that in this case reaction could take place so much more readily. This reaction for forsterite may be represented as follows:

$$\underset{\text{forsterite}}{Mg_2SiO_4} + \underset{\text{calcite}}{2CaCO_3} + SiO_2 = \underset{\text{magnesite}}{2MgCO_3} + \underset{\text{wollastonite}}{2CaSiO_3}.$$

The wollastonite is carried away in solution to be precipitated in the silicated zone just beyond the dolomite or magnesite zone beneath the dikes. In the above reaction the end product has been given for simplicity, but in the actual reaction the reacting solution was probably much more complex and the catalytic agents in the limestone had as great an effect as porosity in causing certain beds to be more completely replaced than others. The full reactions[34] (neglecting the presence of catalysers which do

[34] Although other explanations may later be given, the following seems to be the only one adequate to explain the wollastonite zone farther from the dikes than the dolomite-magnesite zone. Also Spurr has shown that silicic solutions point to a granitic, rather than a femic magma.

not enter the final product) are given below:

$$9(MgO)_2SiO_4 + 3SiO_2 + 12H_2O = 6H_4Mg_3Si_2O_9$$
forsterite — serpentine

$$3SiO_2 + 3CaCO_3 = 3CaSiO_3 + 3CO_2$$
Wollastonite — removed in solution

$$6H_4Mg_3Si_2O_9 + 3CO_2 = 3MgCO_3 + 5H_4Mg_3Si_2O_9 + 2SiO_2 + 2H_2O$$

$$3MgCO_3 + 3CaCO_3 = 3(CaCO_3 \cdot MgCO_3)$$
solution — dolomite

$$15CaCO_3 + 15SiO_2 = 15CaSiO_3 + 15CO_2$$
magmatic silica — Wollastonite — removed in solution

$$15H_4Mg_3Si_2O_9 + 45CO_2 = 45MgCO_3 + 30SiO_2 + 30H_2O$$
serpentine

$$45MgCO_3 + 45CaCO_3 = 45(CaCO_3 \cdot MgCO_3)$$
solution — dolomite

$$30SiO_2 + 30CaCO_3 = 30CaSiO_3 + 30CO_2$$
Wollastonite — removed in solution

In this way the entire rock is converted to dolomite and the wollastonite removed in much the same way as the silica in the formation of magnesite deposits by the decomposition of serpentine in the presence of CO_2. The change to magnesite takes place by the reaction between the dolomite and the $MgCO_3$ molecule of the solutions and results in the replacement of the $CaCO_3$ portion of the molecule by $MgCO_3$ leaving pure magnesite in a matrix of dolomite.

$$3(CaCO_3 \cdot MgCO_3) + 3SiO_2 = 3CaSiO_3 + 3CO_2 + 3MgCO_3$$
Dolomite — Wollastonite — Magnesite removed in solution

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$$\underset{\text{solution}}{H_4Mg_3Si_2O_9} + 3CO_2 = \underset{\text{magnesite}}{3MgCO_3} + 2SiO_2 + 2H_2O$$

The process may be halted in any one of these stages and the earlier it is halted, the easier it is to study and the less value it is as a deposit of magnesite. In the vicinity of the magnesite quarries the activity has continued so vigorously for such a period of time that the limestone zone was narrowed down until the width of the quarries represented the entire width of the carbonate rocks. In the occurrence described by Bain,[35] the changes were not so complete and were very much easier to study.

COMPOSITION OF MAGNESITE FROM DIFFERENT TYPES OF DEPOSITS.

	Sedimentary		Serpentine	Replacement
	Hydromagnesite [36]	Magnesite [37]	Magnesite [38]	Magnesite [39]
SiO_2	0.90	8.51	0.86	0.45
Al_2O_3	0.10	2.94	0.55	tr.
Fe_2O_3	0.09			3.65
FeO	0.45	.....	.....	.....
CaO	0.82	3.36	0.55	0.97
MgO	42.35	38.32	46.94	43.82
CO_2	36.10	40.12	51.10	50.44
H_2O	18.95	6.75	.....	.....
H_2O (Subt.)	1.61	.....	.....	.....
		Composition Range.		
SiO_2	0.54– 1.86	4.75– 9.64	0.23– 1.54	0.45–10.26
Al_2O_3	0.10– 0.67	0.67– 2.94	0.04– 1.98	tr.– 0.48
Fe_2O_3	0.09– 0.15		0.12– 0.20	1.54–5.72
FeO	0.45– 0.60	.....	.....	
CaO	0.68– 2.04	tr.– 4.25	0.03– 1.21	0.20– 8.70
MgO	41.13–42.35	37.19–44.20	45.84–47.16	40.28–45.00
H_2O	18.02–19.05	2.45– 6.75	.....	.....

From a study of the range in composition it will be seen that each type of deposit presents certain characteristics, but that with

[35] G. W. Bain, Bull. 1244 M., Amer. Inst. Min. and Met. Engs., 1923.

[36] G. A. Young, Summary Rept. C. G. S., 1915.

[37] F. L. Hess, *op. cit.*

[38] H. C. Boydell, *op. cit.*

[39] M. E. Wilson, *op. cit.*

the exception of one or two cases the magnesite obtained from veins in serpentine is by far the purest obtainable.

Hydromagnesite is characterized by high water content and low sesquioxides and lime while the ferrous iron is from 4.5 to 5 times as great as the ferric iron. This indicates that the solutions were dominantly reducing during deposition. The high ferrous iron ratio must have been due to the presence of organic or carbonaceous [40] matter which kept down the percentage of oxygen in the water during the precipitation and evaporation. The deposit must also have been buried before evaporation was carried to completion, otherwise oxidation must have inevitably set in. This condition would conform with the higher percentage of water and higher ferrous iron ratio in the Atlin deposits as compared with the lower water and lower ferrous iron ratio in the Kern Co. occurrences, where evaporation seems to have been carried more nearly to completion and oxidizing conditions set up.

The Kern Co. deposits show higher lime content and this is what would be expected if evaporation was carried out until the amount of lime salts in solution approached their solubility constant before the lake was filled with sediments.

The impurities of sedimentary magnesite deposits are mainly a siliceous clay, although, as already stated, low percentages of lime and iron oxide may also occur. That is, the impurities are mainly clastic material.

Magnesite as a vein filling is usually highly ferruginous due to intergrowths of siderite and also isomorphous mixtures of $FeCO_3$ with $CaCO_3$ and $MgCO_3$ in ankerite and breunnerite.

In magnesite derived from serpentine, the lime is seldom over 1 per cent. and the silica, alumina and iron oxides combined rarely exceed 3 per cent. None of these percentages are so high as to be objectionable, but in receiving large shipments, careful examination of the material should be made for large masses of serpentine still adhering to the magnesite.

[40] * H. S. Gale shows a carbonaceous layer characteristic of the top of the magnesite-bearing layers.

The most variable kind of magnesite is that from the replacement deposits and strangely enough the impurities, of all kinds, are the hardest to recognize and yet this magnesite is most widely used. The light colored serpentine, talc and dolomite, which form the chief impurities can readily be detected by analysis or by microscopic examination. The whitish calcined dolomite can sometimes be picked out from the pinkish magnesia after the crude material has been burned, but in many cases this is impracticable, due to the original fine, intimate mixture of the two or redistribution of the lime by calcining at too high a temperature. For these reasons the occurrence and nature of the most objectionable impurity, dolomite, is given in some detail and a suggestion offered to lessen the chance of accepting faulty material.

Effect of Dolomite on Properties of Magnesite.

In the region of the Grenville magnesite deposits,[41] and the same might apply equally well to the other[42] deposits of the replacement type, three definite carbonates,[43] calcite, dolomite and magnesite occur in the rock. In all cases the calcite was completely replaced by dolomite before any determinable quantity of $MgCO_3$ in excess of the dolomite ratio was deposited; polished surfaces of magnesite show varying percentages of dolomite in the rock. Since the melting point of refractory brick is not lowered to a very great extent by even a eutectic mixture of lime and magnesia, the deterioration in quality with rise in lime must be due to the greater chemical activity of the latter. If such is the case, and it seems to be, then as long as the dolomite grains occur only in isolated small patches and the magnesite matrix is of sufficient thickness in between to support any strain to which the brick may be subjected, no injurious effects of a serious nature can be expected by using this grade of material. If the distribution of the magnesite is uniform, dolomite present in

[41] G. W. Bain, *op. cit.*, Bull. 1244 M., Amer. Inst. Min. and Met. Engrs.
[42] K. A. Redlich, *op. cit.*
[43] G. W. Bain, Bull. 1244 M., Amer. Inst. Min. and Met. Engrs., 1923.

amounts up to 25 per cent. of the rock will not affect the quality of the material for ordinary purposes. On the other hand, if the distribution of the magnesite and dolomite is irregular, magnesite rock containing over 15 per cent of dolomite should not be used for work requiring a high temperature under exacting conditions.

Relation of Distribution to Quality of Magnesite.—The reasons for these specifications are that lime, or even calcined dolomite, has a strong affinity for silica; if now a melt carrying silica is contained in a crucible lined with magnesia containing calcined dolomite, the silica will react with the lime of the dolomite to give calcium silicate which is fusible, as well as soluble, in melts far below the melting point of magnesia. The molten silicate will then be at liberty to flow out of the cracks and leave behind a cellular mass which will leak and not have enough strength to withstand any marked strain. As long as the dolomite grains are enclosed in magnesite, the reaction between the lime and silica will stop as soon as in the surface reaction has gone to completion and injurious effects would not be produced.

Amount of Dolomite to Produce Injurious Effects.—When the amount of dolomite does not exceed 15 to 20 per cent. the rock appears to be fairly satisfactory. Such a grade of material from domestic quarries is to be desired much more than sources of supply situated in Europe or elsewhere. The average analyst at the quarries does not understand how to estimate the amount of dolomite in the rock, but he can readily determine the amount of lime in it. Since dolomite contains MgO 21.7 per cent., CaO 30.4 per cent., CO_2 47.9 per cent., the amount of permissible lime can be determined by multiplying the amount of permissible dolomite by 0.304. The lower figure given above should be specified for all high grade material, and in that case rock containing less than 5 per cent. CaO and negligible amounts of insoluble would fulfil the requirements quite satisfactorily. In the case of rock containing 20 per cent. of dolomite, shipments containing about 6.5 per cent. of CaO could be used.

Grading of Material.—The magnesite should be graded as it

comes from the quarry, because mixing pure magnesite with the lower grade material to bring up the "quality" of rock high in dolomite will not affect the lower grade of magnesite in the least, and will serve to lower the quality of the pure magnesite. The poor grade material will remain poor no matter how the composition of the car lot is affected by dilution and the grade of the car is the grade of the poorest piece in it.[44] The only way to raise the quality is to pick out the white dolomite after calcination.

Effects of Treatment.—It is claimed that by calcining at a much higher temperature than is ordinarily used, the lime is rendered "inert." This may appear to be the case, but it can hardly be true in its entirety since in no instance does magnesite high in lime give as good results and durability as the purer grades. What happens at the higher temperature has not been studied in detail, but from the behavior it would appear that a rearrangement of the lime and magnesia took place. The lime is distributed more evenly and is protected from the silica by a veneer of magnesia. When the veneer is corroded off the reaction between the lime and silica takes place rapidly to completion, after which it stops until another patch of lime is exposed. Thus, although corrosion of a magnesia lining in a crucible or an open hearth furnace is slower when the magnesite is treated in this way, the life of the lining is much shorter than when pure material is used.

Nevertheless by this treatment material containing 9 to 10 per cent. of lime can be used and is being used where magnesia containing 5 to 6 per cent. of lime was being used before.

To guard against dangers of unequal distribution of lime, buyers should sample the shipment and also take selected specimens in order to get an approximation towards the maximum lime content which is true measure of the quality of the car lot.

SUMMARY OF CONCLUSIONS.

Magnesite deposits which are being or have been worked can be divided into four types:

[44] This is not always true if the magnesite is to be crushed finer than the smallest dolomite grain in acceptable uniform magnesite.

1. Magnesite as a sedimentary rock,
2. Magnesite as an alteration of serpentine,
3. Magnesite as a vein filling,
4. Magnesite as a replacement of limestone.

Of these only the second and fourth are of economic importance at the present time. The most important and most complex is that which has been termed the replacement type.

Deposits of the replacement type in at least two cases, (Styria and Quebec) are normal limestones replaced by magnesia-bearing solutions emanating from a granite magma. A similar origin seems to apply to the lesser known Washington occurrence. The chemistry of the process as worked out from petrographical studies of the contact zones is outlined in the body of the paper and discussed at considerable length in an earlier paper[45] from which the conclusions are drawn.

The solutions were in the form of silicates when they reached the limestones. The solutes at a certain stage precipitated out as serpentine and talc, rather than as anhydrous minerals as is usually believed to be the case. Almost simultaneously any anhydrous minerals already formed became hydrated.

Reaction between the limestones and dolomites and the silicate-bearing solutions formed magnesite or dolomite, depending upon whether the rock traversed by the solutions was a dolomite, or a limestone.

The wollastonite formed during the reaction was carried away in solution as in the case of the silica in the formation of the magnesite veins in the better known deposits in serpentine.

The sedimentary deposits seem to be formed in salt lakes chiefly by precipitation of the less soluble $MgCO_3$ formed by chemical reaction but probably helped by evaporation.

The vein deposits constitute a variety of the ordinary fissure vein deposits of magmatic origin.

Deposits in serpentine are due to the alteration of serpentine by carbonated waters, seeming, in most cases, to be of mag-

[45] G. W. Bain, *op. cit., Jour. of Geol.*, vol. XXXI., pp. 657–666, 1923.

matic origin. Transportation and selective precipitation are an important feature in forming workable deposits.

Magnesite from deposits of sedimentary origin or from deposits in serpentine is usually very uniform and free from objectionable constituents.

Magnesite from fissure veins is very ferruginous, due to the presence of $FeCO_3$.

Magnesite from replacement deposits is very variable and requires careful sampling. The quality of a shipment is the quality of the poorest piece in it.

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CUPRIFEROUS PYRITIC DEPOSITS, HITACHI MINES, JAPAN.

MANJIRÔ WATANABÉ AND W. R. LANDWEHR.

INTRODUCTION.

THE cupriferous pyritic deposits, which occur as lenticular bodies in stratified or schistose rocks, constitute one of the most important copper resources of Japan. They are especially well developed in the outer zone of southwest Japan,[1] where nearly sixty mines have been worked. In northwest Japan there are only a few examples of this type of deposits, but the great copper mines of Hitachi belong to this type.

The Hitachi mines are located in the southern portion of the Abukuma Plateau, near the Sukegawa station of the coastal railway line connecting Tokyô and Sendai. The country rocks of the mines were greatly metamorphosed by the intrusions of a large batholith of granodiorite and several small igneous bodies. The geologic structure of the whole area is highly complicated and has afforded many interesting problems to Japanese geologists.[2] One of the authors had several opportunities to investigate the geologic features of the mines, and his microscopic study was done in the Tohoku Imperial University, Japan, under the kind encouragement of Prof. S. Kôzu. His research was continued coöperatively in Stanford University, Calif., under the guidance of Prof. C. F. Tolman. The writers' hearty thanks are offered to both professors on this occasion.

1 Watanabé, M., ECON. GEOL., vol. 18, p. 173. 1923.

2 Oyu, M., "On the Occurrence of Andalusite in the Environs of the Hitachi Mines," Sci. Rept. Tohoku Imp. Univ., Ser. II., vol. 1, 1914; Tameda, B., and Yamane, S., "Geology of a Part of Taha Range," 1904; Watanabé, M., "Some Contributions to the Modes of Occurrence of Ottrelite near the Hitachi Mines," 1916.

GEOLOGICAL FORMATIONS.

The rocks[3] of the mining area consist of a thick series of crystalline schists and amphibolite, including epi-diorite, a batholithic body of granodiorite with its apophyses, small stocks of dioritic rocks, an irregular mass of micro-granodiorite, and a number of aplite and pegmatite dikes.

The crystalline schists and amphibolite constitute the chief country rocks of the ore deposits. They strike northeast and dip toward the northwest at angles from 50 to 70 degrees. However, local disturbances, accompanied by strike and oblique faulting, are common. The rocks consist mainly of green or pale-green schistose varieties, which have been called amphibolite and anthophyllite-actinolite schists.[4] Epi-diorite, in all transitional stages to amphibolite, is also common. In many places, however, these green rocks are replaced by snow-white sericite schist or by brown mica schist, sometimes with red spots of andalusite.[5] Nodular spots of cordierite, 0.5 to 1.5 cm. in diameter, are also found in large numbers in some of these mica schists and anthophyllite-actinolite schists. The geologic age of these rocks is not known, although it is certain that they are older than the Upper Carboniferous limestone appearing near the area.

The granodiorite, which occurs near the northern boundary of the mines, is a portion of a batholith that is a fundamental element of the Abukuma Plateau. The rock varies greatly in different parts of the continuous mass, being distinctly schistose near the mines.[6]

The boundary between the granodiorite and the schistose rocks is quite irregular. In the mining area, the schistose formations, with the enclosed ore bodies, extend into the granodiorite mass, and a promontory of igneous rock projects into this part of the schistose formations, as is shown in Fig. 48. Furthermore, stocks of dioritic rocks and irregular masses and dikes of micro-

[3] Man. Watanabé, *Journ. Geol. Soc. Tokyô*, vol. 27, 1920, and vol. 28, 1921.
[4] B. Tameta and S. Yamane, *loc. cit.*
[5] M. Oyu, *loc. cit.*
[6] Watanabé, M., *loc. cit.*

granodiorite, aplite, and pegmatite all occur near this projection, and intensely metamorphosed rocks with characteristic contact minerals also occur here. Such rocks as two-mica-andalusite-fels, andalusite-sericite-fels, cordierite-mica-fels, cordierite-anthophyllite-fels, and others,[7] are found in association with sericite schist, biotite schist, and anthophyllite-actinolite-schist. The distribution of these highly metamorphosed rocks is rather regular; they are largely confined within an area having a form somewhat like a candle flame.

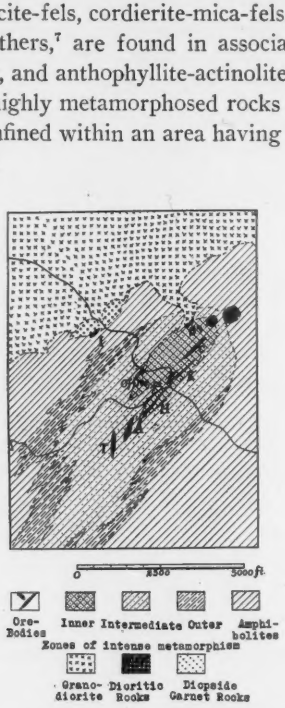

FIG. 48. Geologic map of Hitachi Mines. S, Sasame; C, Chûsei; K, Kammine; H, Honkô; A, Akazawa; T, Takasuzu; I, Irishiken.

Surrounding this area of contact-metamorphosed rock, there is a second zone where the anthophyllite-actinolite schist and less metamorphosed amphibolite predominate. This zone is, in turn, surrounded by a third zone, in which sericite schist is abundant. Thus, the zonal arrangement of these metamorphosed rocks may be compared, in shape, to a candle flame, formed of inner, inter-

[7] Oyu, M., *loc. cit.*

mediate, and outer zones. When thought of in this manner, the axis of the flame coincides with the direction of the rock strike, and the core of the candle corresponds in position to the complex association of igneous rocks, which have been mentioned above. These relations are illustrated in Fig. 48.

Apart from these metamorphic zones, there is another small area where the amphibolite, intruded by granodiorite, has changed into pale-green rocks with diopside and garnet. This type of rock is found in an intimate association with aplitic apophyses of the intrusive body.

STRUCTURE AND TEXTURE OF THE ORE DEPOSITS.

The important ore deposits of the Hitachi mines are divided into seven groups, named Sasame, Chûsei, Kammine, Honkô, Akazawa, Takasuzu, and Irishiken. All but the last occur in a zone that is approximately parallel to the strike of the country rocks. This important zone of ore deposits occupies a position that corresponds to the axis of the flame-shaped metamorphic zones. The distance from the igneous rocks to the ore deposits, except those of the Irishiken group, increases in the order given, the first mentioned one being at the contact between the igneous rocks and the schistose formations.

Each deposit has a lenticular shape and is generally conformable to the country rocks. But in certain places, the deposits cut the planes of schistosity of the country rocks. It is quite certain, therefore, that these deposits are not of sedimentary origin.

The ore consists essentially of pyrite, pyrrhotite, chalcopyrite, and sphalerite. Small amounts of magnetite and galena are found. Limonite, malachite, azurite, native copper, and chalcanthite are observed only as oxidation products. Marcasite occurs in some ores as a secondary mineral.

The amount of gangue minerals is small. These are chiefly sericite, chlorite, light-brown mica, quartz, barite, and rarely carbonates. Hornblende and cordierite are also found in some ores, but they are always the remnants of the replaced country rocks.

The relative amounts of the various minerals differ widely in different deposits and in different parts of the same deposit. In general, the ore bodies near the igneous rocks are rich in pyrrhotite and chalcopyrite and poor in pyrite and sphalerite as in the Sasame and Chûsei groups.

In the deposits distant from the intrusive rocks, on the other hand, pyrite and sphalerite increase in amounts as pyrrhotite and chalcopyrite decrease. Thus, in the Akazawa and Takasuzu groups, which are farthest removed from any of the igneous bodies, pyrrhotite rarely occurs, chalcopyrite is in small amount, and pyrite is the most essential component. Sphalerite is mostly less abundant than pyrite. Barite is intimately related with sphalerite; where one increases so does the other.[8]

The texture of the ores also varies in different deposits, and in general, ores near the intrusive rocks are heterogeneous and coarse-grained, whereas, those far from the igneous bodies are commonly homogeneous and fine-grained. For instance, the Sasame and Chûsei deposits, nearest to the igneous rocks, occasionally contain large grains of pyrite, 1 to 2 cm. in dimension, embedded in the matrix of pyrrhotite, chalcopyrite, or both. In places, large crystals of pyrite, 5 to 8 cm. along the edge, have been observed. But even in these deposits nearest to the intrusive masses, some portions of the ores have a fine-granular texture, and in many cases, such fine-grained ores are found side by side with the ores containing large crystals of pyrite. Such a heterogeneity is often observed in the same hand-specimen from these deposits.

The ores from the deposits distant from the igneous rocks, such as those of the Akazawa and Takasuzu groups, are commonly made up of a homogeneous mosaic of pyrite grains, ce-

[8] According to J. Akaoka (*Jour. Geol. Soc. Tokyô*, vol. 27, p. 434, 1920), the average percentages of Zn and $BaSO_4$ in the ores, worked during the March of 1919 are as follows:

	Sasame	Chûsei	Kammine	Honko	Akazawa	Takasuzu	Irishiken
Zn.....	0.79	1.01	1.01	1.31	1.50	3.57	1.10
$BaSO_4$...	0.22	0.30	0.85	0.90	1.10	1.85	0.12

mented by chalcopyrite, sphalerite, or both. But even in these ores, heterogeneity is sometimes produced by irregular veins, rich in chalcopyrite, that traverse the homogeneous mass.

The ore deposits of the Irishiken group lie at some distance from the main zone of ore bodies near the margin of granodiorite in the area characterized by the development of diopside and garnet. The ores from this group are characteristic of those found near the igneous rocks, although the amount of pyrrhotite is less than in the ores from the Sasame and Chûsei groups.

Open cavities are not found in the ores, except in those near the surface. No structures indicating the fissure-filling origin of the deposits, such as drusy cavities, symmetrical banding, or brecciated structure, have been observed.

MINERAL RELATIONS.

Pyrite, the oldest of the primary minerals, occurs as cubic crystals scattered through other minerals, or when the crystals are so nearly spaced that each hinders the development of the other, it makes up a mosaic of xenomorphic grains. The interstices are filled with chalcopyrite, pyrrhotite, sphalerite, or their aggregates, which often replace the pyrite from the margin as microscopic offshoots or embayments.

In most cases, the sphalerite had completed crystallization before chalcopyrite and pyrrhotite finished their development, and the former is traversed by offshoots of the latter minerals. In general, however, the contemporaneous origin of these three minerals is inferred from their intimate association even in small interspaces and minute offshoots.

Generally, the formation of these mixed ores seems to have followed immediately after the impregnation of the rocks by pyrite, although in some cases, the pyrite remains in a disseminated condition without being cemented by other ore minerals, which elsewhere replaced the rock minerals interspacing the pyrite grains. It seems to the writers that pyrite, chalcopyrite, pyrrhotite, and sphalerite were derived from the same solutions,

but for some reasons, as yet unknown, pyrite finished its crystallization while the other minerals were still in solution.

In the ores near the intrusive bodies, on the other hand, fine veinlets of pyrrhotite, chalcopyrite, and sphalerite are frequently found to traverse the other minerals, or each other, irrespective of the previous texture, though in general the pyrrhotite veins seem to be later than the others. These veinlets represent, apparently, a later injection of mineralizing solutions from the magmatic source.

Other features of interest are found in the ores near the igneous rocks. Under high magnification of the microscope, abundant minute grains of chalcopyrite are detected in crystals of sphalerite, a feature so frequently noted by those who have studied under the microscope mixed ores containing sphalerite. In some cases these inclusions are arranged in extreme regularity as rows of dots parallel to the crystallographic orientation of sphalerite, or they may be irregular in shape and irregularly distributed throughout the sphalerite. Thompson[10] has also described the same structure in the ores from Ducktown, Tenn. In his case, chalcopyrite appeared in relatively large spots, which were arranged along the cleavage planes of sphalerite. He concluded that the spots were formed by replacement of sphalerite along the cleavage. It may be possible, however, that these spots were derived from the copper and iron sulphide, which were included in sphalerite as solid solutions at higher temperatures or under different conditions. According to Young and Moore,[11] the iron content in chalcocite combines with chalcocite to separate as chalcopyrite under the high pressure of hydrogen sulphide. Similarly, it may be possible that the iron and copper sulphides, which might have been contained in sphalerite in small amounts, would have separated by changes of conditions of physico-chemical equilibria. This assumption is favored also by the following observation.

In the same ores of the Hitachi mines, in which chalcopyrite

[10] A. P. Thompson, ECON. GEOL., vol. 9, 1914, 153.

[11] S. W. Young and N. P. Moore, ECON. GEOL., vol. 11, 1916, 349.

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spots are found in sphalerite, dendritic bodies and skeleton crystals of sphalerite are observed in chalcopyrite under high magnifications. They are never found in other minerals, and although the replacement of pyrite by sphalerite is not rare, the replacing sphalerite assumes a quite different form from the inclusions described above and usually occurs as small veinlets or irregular projections. Accordingly, there is some reason to suspect that these skeleton crystals of sphalerite in chalcopyrite might have been derived by the dissociation of the impure chalcopyrite.

Still another suggestion, that the two minerals were deposited simultaneously, might explain this phenomenon. It is difficult, however, by this assumption to understand why chalcopyrite and sphalerite do not form mixtures, in which the relative amounts of the two minerals are approximately uniform throughout the ore, but they form two different mixtures, namely, sphalerite with a small amount of chalcopyrite and chalcopyrite with only a negligible amount of sphalerite.

Galena and magnetite occur in such small amounts that their relation to other minerals is not determinable.

The order of succession of the essential ore minerals, which have been described, is in accordance with the conclusions, arrived at by Thompson[12] from the study of sulphide ores from many localities and by Bastin[13] from the study of mixed ores from the Gilpin Co., Colo. However, the whole course of events is more complicated in the Hitachi mines.

Among the essential gangue minerals, sericite is sometimes replaced by chalcopyrite and pyrrhotite along the cleavage planes, but more abundantly the mineral appears as irregular veins through the ore minerals. This mineral was doubtless formed simultaneously with the ore minerals, although its development continued after the ore deposition. Barite is also found often replaced by ore minerals, whereas quartz occurs more usually as irregular grains that have replaced chalcopyrite in preference to other ore minerals.

[12] A. P. Thompson, *loc. cit.*

[13] E. S. Bastin, and J. M. Hill, U. S. Geol. Surv. Prof. Paper 94, 1917.

Pyrite and marcasite are frequently observed as secondary minerals in ores that show no other indication of oxidation. The two minerals occur usually in association and are often difficult to distinguish from each other. The secondary pyrite occurs as fine veinlets which traverse all other minerals. Where the secondary pyrite replaces the margin of quartz grains that are enclosed in primary pyrite, or where it occurs as veinlets in quartz, it might be mistaken for primary pyrite, but when it is carefully observed, minute cavities separate the secondary pyrite from the primary crystals (Fig. 49, *A*).

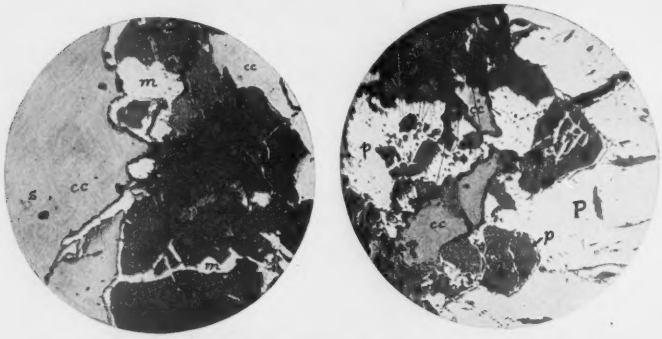

FIG. 49, *A*. Showing the secondary pyrite (light) replacing the margin of quartz grains (gray) enclosed in primary pyrite. × 55. *P*, primary pyrite; *p*, secondary pyrite; *cc*, chalcopyrite; *q*, quartz.

FIG. 49, *B*. Showing marcasite (light) replacing chalcopyrite (light gray) and quartz (dark) along fissures and mutual boundaries. × 100. *P*, primary pyrite; *p*, secondary pyrite; *cc*, chalcopyrite; *s*, sphalerite; *q*, quartz.

Marcasite appears more frequently as irregular bodies with more or less spherical surface. Where it appears along fissures, it shows a tendency to swell into spherical bodies in many places (Fig. 49, *B*) without forming continuous veins.

In some cases, the successive replacements of pyrite by chalcopyrite, of chalcopyrite by quartz, and of quartz by marcasite are

observed, the earlier minerals remaining in part as replaced remnants (Fig. 50). This sometimes results in the formation of marcasite in the place originally occupied by pyrite. But otherwise, there is no evidence of direct replacement of pyrite by marcasite.

FIG. 50. Showing the successive replacement of pyrite (*P*), by chalcopyrite (*cc*), of chalcopyrite by quartz (dark) and of quartz by marcasite (*m*), partly changing into secondary pyrite (*p*), *s*, sphalerite. × 30.

On the other hand, reverse changes of the margins of the marcasite into pyrite is occasionally observed. The marcasite in the center shows the characteristic appearance of fibrous aggregate and is easily attacked by nitric acid, but the marginal portions have a massive appearance and are attacked only slightly by the same acid.

RELATION BETWEEN DYNAMIC METAMORPHISM AND STRUCTURE OF ORE DEPOSITS.

The lenticular shape of this type of deposit is often believed to be the result of the deformation of the ore bodies caused by the dynamic metamorphism that produced the schistosity of the country rocks. This seems probable in some deposits of other localities [14] but the writers do not believe this is the case at the

[14] W. Lindgren, and J. D. Irving, "Rammelsberg Ore Deposits," ECON. GEOL., vol. 6, 1911, 303. W. H. Emmons, "Milan Mine," U. S. Geol. Surv. Bull. 432, 1910, 62.

Hitachi mines. It is true that the ores have suffered some external stress as is shown by the deformation of some large crystals of pyrite. These have facial angles, which deviate by 1 to 4 degrees from the right angle, yet the crystals are not granulated into separate pieces even at the sharp edges. The deformation is probably of plastic nature, and the amount of it is relatively small. It is well known, however, that pyrite has a stronger resistance to deformation than chalcopyrite and pyrrhotite.[15] Therefore, it may be supposed that, although the deformation of pyrite is small, the ore bodies might have changed their shape fundamentally by greater deformation of chalcopyrite and pyrrhotite. Such is an opinion once proposed by T. Katô.[16] But evidence opposed to this is offered by some crystals of pyrite from the Sasame ore bodies. Each crystal is divided into several isolated grains by veins of chalcopyrite that replaced the pyrite along the fractures. The grains that originally belonged to a crystal still retain the cubic form as a whole, and all have nearly the same crystallographic orientation. If the ore bodies had been severely distorted in any way, these grains would have been removed from one another and would have taken random arrangement.

Other evidences of granulation or marked deformation of the ore bodies were specially looked for by the writers. For instance some pyritic ores disseminated in country rock exhibit a schistose appearance. This is, however, commonly caused by the parallel arrangement of the silicate minerals of the original rock, especially of sericite flakes, which remained partly unreplaced. The grains of pyrite are scattered through them without any tendency to elongate in the direction of schistosity. Accordingly, should the silicate minerals between the pyrite grains be entirely replaced by chalcopyrite, pyrrhotite, sphalerite, or their combinations, the schistose appearance would be totally destroyed. Such is a common case, in which the replacement has advanced more perfectly.

[15] F. D. Adams, *Jour. Geol.*, vol. 18, 1910, 489.

[16] T. Katô, personal communication.

In other instances, grains of pyrite are arranged in parallel folded laminæ along planes of schistosity. In such cases, it seems at first glance that the ores have been deformed together with the enclosing rock; but this structure may be regarded as the result of replacement along schistosity planes that had been formed before the deposition of the ores. Moreover, the massive ores in the same rock grade into the parallel laminæ of ores and the former often cut the schistosity planes, showing no indication of deformation.

Similar evidences for ore deposition being later than the dynamic metamorphism were described also by J. Akaoka.[17] Evidence of recrystallization is also wanting. On the contrary, some ores have large crystals of pyrite, side by side with fine-grained aggregates of the same mineral. Besides, the microscopic offshoots of chalcopyrite and sphalerite cutting the pyrite grains evidently show that there was a certain order of mineralization among the component minerals. If the ores have suffered recrystallization, all the grains of the same mineral, for instance of pyrite, should have a nearly uniform size. Therefore, the textures above mentioned are believed by modern petrologists to be against the recrystallization of the mineral aggregates.[18] Furthermore, some of the lenticular masses are developed oblique to the schistosity.

In short, the ores of the Hitachi mines have been deformed only to a relatively small extent, and the deposits retain in large degree the original form and texture.

RELATION BETWEEN ORE DEPOSITS AND ROCK ALTERATION.

As has been stated, the distribution of ore deposits of the Hitachi mines has an intimate relation to the arrangement of the highly metamorphosed rocks, which contain many contact minerals such as cordierite,[19] andalusite, anthophyllite, sillimanite,

[17] J. Akaoka, *Jour. Geol. Soc.*, vol. 27, 1920, 433.

[18] U. Grubenmann, "Kristallinen Schiefer," 1910, 89.

[19] Detailed descriptions of this mineral will be given by M. Oyu, in Sci. Rept. Tohoku Imp. Univ., Ser. III. in the number, which will soon appear.

biotite, and rarely garnet. Cordierite appears as xenomorphic nodules, including abundant grains of other minerals in a poikilitic manner, and shows complicated twinning. Also andalusite has crystalline outlines only rarely, and usually occurs as irregular grains, sometimes partly changing into aggregates of sillimanite. Cordierite of sericite type,[20] and andalusite of chiastolite type, both of which are characteristic of contact metamorphosed clay slate, have not been found. Such modes of occurrence of cordierite and andalusite as well as the formation of anthophyllite and sillimanite suggest that these rocks were metamorphosed under high pressure and high temperature.[21]

From the chemical point of view, on the other hand, the rock alteration of the Hitachi mines belongs to the type called magnesia metasomatism by Goldschmidt.[22] As was mentioned by him, this type of metasomatic replacement of silicate rocks is intimately connected in many cases with the formation of sulphide ore deposits. Examples are especially numerous in the Scandinavian countries, where many deposits are found that are similar to those of the Hitachi mines.

According to Eskola,[23] for instance, the leptite formation in the Orijarvi mining district has suffered intense metasomatism around a batholith of gneissic granite, and the metamorphism is characterized by the development of cordierite and anthophyllite. The chalcopyrite deposits are found in this formation in the places where the rock was highly metamorphosed and was changed into the aggregates of these two minerals and quartz. Also in the Falun pyritic deposits, according to Geijer,[24] the leptite formation grades into a cordierite-bearing mica schist, which in turn passes into the cordierite-anthophyllite-quartzite that contains the ore bodies. Cordierite is reported also from the pyritic deposits of Bodenmais by Weinschenk.[25]

20 Y. Kikuchi, *Jour. Coll. Sci. Imp. Univ. Japan*, vol. 3, 1890, 337.
21 Grubenmann, *op. cit.*
22 V. M. Goldschmidt, ECON. GEOL., vol. 17, 1922, 105.
23 P. Eskola, *Bull. Comm. Geol. Finland*, No. 40, 1914.
24 Geijer, ECON. GEOL., vol. 15, 1921.
25 E. Weinschenk, *Zeits. f. prakt. Geol.*, vol. 8, 1900.

In the case of Orijarvi deposits, Eskola claimed that the sulphide minerals were formed contemporaneously with silicate minerals. Also at the Hitachi mines according to Katô,[26] the deposits are clearly of contact metamorphic origin. He thinks that these deposits are evidently connected genetically with granitic rocks, to the intrusion of which the metamorphism of the rock complex enclosing the deposits is largely due. With this opinion the writers agree in general, but at the same time they believe that the formation of ore deposits is not the result of the same process which produced the cordierite, or andalusite. The main zone of ore deposits does not follow the occurrence of cordierite; some rocks rich in cordierite are free from the ores while some ore bodies are developed in the rocks in which no contact mineral is found.

On the contrary, the veinlets of sulphide ores frequently traverse the nodules of cordierite and grains of andalusite, and in the ores these minerals remain only as irregularly shaped remnants of replacement. This clearly shows that the formation of ores was later than the typical contact metamorphism.

On the other hand, the gangue minerals, which always accompany the sulphide ores and are believed to be of contemporaneous origin, are sericite, light-brown mica, barite, quartz and calcite, and other carbonates. Most of these minerals are characteristic of ore deposits and rock alterations at intermediate temperatures, caused by the action of ascending aqueous solutions, and some of them have never been found elsewhere in typical contact metamorphic deposits. The ore deposits of the Hitachi mines are, therefore, believed to have been formed by the hydrothermal metasomatism, which followed the contact metamorphism of the country rocks.

The intimate association of sericite schist and the ore deposits is especially characteristic in these mines. This rock is developed abundantly not only in the outer zone of metamorphism but also in the inner zone as a hanging or foot wall of the ore bodies. Especially when the rock contains biotite, it serves as a good

[26] T. Katô, *Journ. Geol. Soc. Tokyô*, vol. 22, 1915, 11.

indicator for prospecting the ores. Under the microscope, the rock is frequently seen to contain notable amounts of fluorite and some needles of rutile, together with pyrite. This seems to indicate the action of mineralizers in the formation of this rock. Even when the sericite schist is far from the ore deposits, it usually contains a large amount of pyrite. Accordingly, several mines were worked, besides the Hitachi mines, in the district in or near the sericite schist, although they produced little or no copper, except from the small mines of Suwa.

Not only in the Hitachi mines, but also in the Besshi mine, which is the largest of this type of deposits in southwest Japan, the intimate relation between the sericite schist and the ore bodies has been noticed, and a similar relation between the sericite phyllite and the ore deposits is observed in the pyritic copper deposits of the Hibira and Makimine mines,[27] where the sericitic rock is confined to the ore-bearing zone.

RELATION BETWEEN ORE DEPOSITS AND IGNEOUS ROCKS.

Among the igneous rocks of the Hitachi mines, the evidence of dynamic metamorphism is pronounced in the granodiorite, scarce in diorite, and quite wanting in microgranodiorite, aplite, and pegmatite. The diorite is clearly traversed by apophyses of microgranodiorite in the working No. 1 of Sasame. Accordingly, the order of intrusion is most probably, counting from the oldest, granodiorite, diorite, microgranodiorite and aplite, and pegmatite.

The granodiorite consists essentially of quartz, andesine, hornblende, biotite, and small amounts of other minerals. Pyrite, pyrrhotite, or chalcopyrite has not been observed in this rock, and the only ore minerals in the rock are magnetite and hematite, both in small amounts. In some parts, the rock is clearly cut by the wedge-shaped extensions of the ore bodies, which further branch into ore veins traversing the rock. On both sides of such veins, the rock is highly chloritized in narrow zones.

The diorite appears in irregular bodies resembling stocks. It

[27] T. Katô, *Journ. Geol. Soc. Tokyô*, vol. 22, 1915, 18.

is markedly differentiated. In some places, the rock is fine-grained, in others, it is coarse textured. Banded structure, produced by alternation of the different facies is occasionally observed, and in some places slight schistosity is recognized. The typical variety consists of hornblende and plagioclase as essential components; in some places it contains abundant quartz, in other places, hornblende predominates over plagioclase.

An important feature of the diorite is that it contains notable amounts of pyrite, in addition to magnetite. These minerals occur as irregular grains, sometimes replacing the essential components along the fissures and cleavage planes, but more usually filling the interstices. They were evidently the last minerals to be formed. However, their distribution is almost uniform throughout the greater portion of the whole body. Even when the diorite occurs as thin platy apophyses along the schistosity planes of amphibolite, free from the ores, the diorite contains pyrite and magnetite. No chloritization or other alteration is observed around the ore. It would be more probable, therefore, to regard these specks of pyrite and magnetite in diorite as the last product from the magma, than to assume that they were introduced later from without.[28]

The microgranodiorite, which is intrusive into both the diorite and amphibolite, is much more differentiated than the diorite. Most of it consists of fine-grained aggregates of quartz, plagioclase, biotite, hornblende, and a small amount of orthoclase, but the rock grades through micro-adamellite, into granophyre and aplite. In an extreme case, the rock grades even into an aggregate of quartz with little or no felspar. Notable amounts of epidote, rutile, chlorite, calcite, and fibrous hornblende also occur in some parts of the rock, and they give it a characteristic appearance.

In addition to these minerals, pyrite, pyrrhotite, and chalcopyrite occur rather abundantly in this rock. These ores have two different modes of occurrence. A smaller portion of them

[28] Ref. C. F. Tolman and A. F. Rogers, "Magmatic Sulphide Ores," Stanford Univ. Publ. Series, 1916.

are scattered uniformly throughout the whole body of this rock as isolated grains or small patches, in some of which all stages of replacement of feldspar and quartz by ores can be observed. In the marginal portion of the ore patches, feldspar remains as idiomorphic crystals in the ore, and the quartz is replaced. In the central portion, however, feldspar is also replaced. Such grains and patches of ore are completely surrounded by the constituent minerals of the rock, and the distribution of this type of ore is not related to fractures in the rock, and is not accompanied by chloritization. They seem to be the last products of the magma, and not to have been introduced from without. However, the occasional association of fibrous hornblende and rutile needles with these ores in the microgranodiorite may indicate that some pneumatolytic process played a rôle in their formation. Probably they were produced in the pneumotectic stage of that magma.

The other, and most abundant, type of ore in the microgranodiorite occurs as irregular veins and masses accompanied by distinct but thin zones of chloritization. Almost all the minerals nearest to the ore are converted into chloritic aggregates; more distant, plagioclase is the only mineral that has suffered alteration, quartz and biotite remaining fresh. Still farther from the ore, chloritic substance is developed in but small amount along the cleavage planes of plagioclase. The ore of this type is found in a special portion of the microgranodiorite, and they are parts of the main deposits of the mine. It is clear, therefore, that they were introduced when the main deposits were formed and that the formation of the main ore deposits was later than the consolidation of this rock.

No evidence of dynamic metamorphism is observed in the microgranodiorite; the ores were very probably introduced after the orographic movements were completed. This is further evidence against the assumption that the ore bodies were greatly metamorphosed by that process after their deposition.

The aplite and pegmatite occur as numerous veins and small dikes in the northeast end of the Hitachi mines. Some of them

contain, as essential components, such minerals as tourmaline, and garnet, which are characteristic of pegmatitic rocks; others consist chiefly of idiomorphic crystals of cordierite and quartz, with or without feldspars. This special type of pegmatite, containing cordierite, often grades into quartz veins. This rock is intimately related to the rich ore bodies, and the rock is occasionally found as irregular masses, largely replaced by the ores.

If the general assumption be accepted that all of these intrusive rocks were derived from the same original magma, the later intrusions may be regarded as derived from the residual magmas of the earlier intrusion, and the ore bodies may be considered to have had their origin in the residual solutions of the whole magma, which were finally injected into the adjacent schistose rocks. Successive changes in the nature of the ore minerals, in their amounts, and in the degree of differentiation of rocks in each stage of intrusion seem to be in accordance with this assumption.

Another interesting point is that these various types of igneous rocks as well as the ore deposits were all developed in the particular area on the margin of the granodiorite, which occurs as a large batholith. It seems that the residual components of the granodioritic magma were accumulated, for some unknown reason, in this part and were successively injected.

The development of the metamorphic zones also seems to have intimate relations with the accumulation of these residual components of the original magma. The distribution of contact minerals is not uniform around the margin of any intrusive rock, but is, as has been stated, compared in shape to a candle flame, the core of which corresponds in position to the complex association of the later intrusive rocks, where the residual magmas are believed to have accumulated. Only a small area near the Irishiken ore bodies, which is characterized by the development of garnet and diopside, is on the margin of granodiorite, far from the igneous complex above mentioned. Also here, however, numerous apophyses of granodiorite, much more differentiated than the mother rock, shows that there were some special conditions which favored the accumulation of the magmatic residue.

TABLE I.

Original magma
Metamorphic rocks
Igneous Rocks and Ore Deposits
(rock types)
(non-metallic components)
(metallic components)
Granodiorite non-differentiated
quartz, feldspar, biotite, hornblende, etc.
hematite and magnetite
Diorite differentiated
feldspar, hornblende, etc.
magnetite and pyrite
Microgranodiorite highly differentiated
quartz, feldspar, biotite, hornblende, etc.
magnetite, pyrite, chalcopyrite, and pyrrhotite
Aplite, pegmatite, and ore-deposits
End-products of differentiation
tourmaline, garnet, feldspars, cordierite, quartz, barite, sericite, carbonates, etc.
pyrite, chalcopyrite, pyrrhotite, and sphalerite.
Diopside
Garnet
Cordierite
Andalusite
Sillimanite
Biotite
Anthophyllite
Actinolite
Contact minerals
Rutile
Fluorite
Sericite
Chlorite
Quartz
Pneumatolytic and Hydrothermal minerals

From what has been stated, it will be seen that in the Hitachi mining district, any one igneous rock is not to be regarded as the source of ore deposits and of contact and hydrothermal metamorphism, but the entire suite of events is related to the whole series of intrusion, which probably required a long time. At the beginning of intrusion, dynamic metamorphism was still active and this might have favored the accumulation of the residual magma. Then the intrusions of this residual magma followed on one side, while on the other side the contact metamorphism was accomplished by the materials that escaped from this magma in the form of gaseous and liquid solutions. Finally, a residual mass, rich in mineralizers and sulphides, accumulated with the lowering temperature. Some of these components were intruded as aplite and pegmatite, and the remainder was injected as ore-bearing solutions.

As the ore-bearing solutions take a much longer time to crystallize than igneous bodies, they traveled for great distances mainly along the schistosity planes and fissures. But as they traveled farther from the original place of accumulation, the temperature must have gradually decreased. This seems to be the cause of the relatively regular changes of mineralogical composition and textures of the ore bodies according to the distance from the complex association of the igneous rocks.

The whole relation may be diagrammatically shown in Table I.

SUMMARY.

The ore bodies of the Hitachi mines are typical bedded replacement deposits of pyrite and chalcopyrite, mixed with some pyrrhotite, sphalerite, and small amounts of sericite, quartz, barite, chlorite, and carbonates. They occur near the contact between a large batholith of granodiorite and schistose formations of unknown age, older than the upper Carboniferous.

A complex association of small intrusive bodies, all highly differentiated, is developed in a particular area near the margin of the granodiorite. They are younger than the granodiorite and are believed to have originated from the residual parts of the granodiorite magma.

Intimately related to these igneous rocks, groups of highly metamorphosed rocks, containing cordierite, andalusite, anthophyllite, biotite, and sericite, are distributed in three zones. Their arrangement may be compared in shape to the inner, intermediate, and outer zones of a candle flame.

The ore deposits occur mainly in the zone that corresponds in position to the axis of the above-mentioned metamorphic zones. The northeast end of the ore zone is in contact with the complex association of intrusive rocks, and the other end of the ore zone is about 5,000 feet distant from the igneous bodies.

The mineralogical composition and the texture of the ores vary according to the distance from the igneous rocks. Nearer to the igneous rocks the ores are coarser-grained and more heterogeneous. The amounts of pyrrhotite and chalcopyrite increase as the distance from the igneous rocks decreases, whereas, those of pyrite and sphalerite increase with the distance.

The order of mineral deposition is complicated. It began with the precipitation of pyrite crystals and was immediately followed by the deposition of chalcopyrite, pyrrhotite, and sphalerite, that filled the interstices of the pyrite. Veins of chalcopyrite, pyrrhotite, or sphalerite were formed subsequently. Possibly some of the chalcopyrite and sphalerite were produced by the later dissociation of the other minerals which contained them.

Secondary pyrite and marcasite were formed in some ores, probably by descending solutions.

The formation of the ore bodies is clearly later than the development of contact minerals, such as cordierite and andalusite, and is approximately contemporaneous with the development of quartz, sericite and barite.

The ore bodies have suffered the effects of dynamic metamorphism only to a small extent, and the original texture and structure are largely preserved without strong deformation or distortion.

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PETROLEUM POSSIBILITIES OF WESTERN OREGON.

WARREN DU PRE SMITH.

In the world-wide search for new petroleum fields, persistent efforts are being made to locate petroleum deposits in the state of Oregon. In view of the general belief among some geologists and laymen, in spite of all negative reports, that there must be commercial deposits within its borders, and in view of the fact that wildcatting of the wildest kind is being carried on at the present time in sight of the State University, in which operation witchsticks and even religion are being invoked, it might be of interest to geologists to have the latest news from this field. The writer of this paper is well aware that many competent geologists have examined parts of this state and to these men he does not claim to bring anything essentially new. However, he may bring some different interpretations which might be of value, and to others who may not be familiar at all with this region this summary may offer some assistance in arriving at an evaluation of this prospective territory.

It is pertinent to mention the geological work that has been done in this part of the state with particular reference to petroleum. Of course, all the geological work from the time of Condon bears indirectly on this question, but of those who have worked particularly upon the subject, Chester Washburne was perhaps the first and by his contribution perhaps the best known. Even today our best guide is his "Reconnaissance of the Geology and Oil Prospects of Northwestern Oregon."[1] The main conclusions of this report have not been found in error. Of course, some of his opinions with reference to stratigraphy and palæontology have had to be modified as a result of more recent detailed work, but such changes reflect no discredit upon the early work of that investigator.

[1] U. S. Geol. Surv. Bull. 590.

The next important contribution bearing directly upon petroleum in western Oregon is that of the firm of Harrison and Eaton,[2] consulting petroleum geologists. The field work for this report was directly in charge of Mr. Clarence Osburn, assisted by Mr. Ewart G. Sinclair, Mr. Frank Kelsey, and the writer. This report, for the kind of public and for the special purpose desired, may be considered satisfactory, but inadequate from the point of view of the professional geologist. The writer of the present paper wishes to correct one error in this report which he has not yet had the opportunity to do. It is stated in the text that the preparation of the table of stratigraphy west of the Cascade Range in Oregon was largely his work, but the writer did not see the report or his revised table before it went to press. In this table it is stated that the Chico is not found in Oregon. Any one familiar with the geology of southwestern Oregon knows that this is incorrect. Diller, the veteran field geologist of Oregon, has mentioned many localities where Chico beds outcrop in this state.[3] With the main conclusions of the report by Harrison and Eaton, the present writer is in general agreement, but he feels that not enough detailed field work has been done to justify their positive negative conclusions.

The most important conclusion of this report, in the opinion of the writer, is that the Newport region offers the best possibilities of finding oil and the writer believes that further prospecting north and east of Newport may reveal a favorable structure, which with other favorable features might justify one or more wildcat wells in that region.

Other valuable private work has been done which has not been permitted publication. I might mention the work of my colleague, Dr. E. L. Packard, who has gone over much of this ground during past field seasons, also that of Dr. Roy Dickerson, now in the Philippine Islands. And there may be several others repre-

[2] "Investigation of Oil and Gas Possibilities of Western Oregon," Oregon Bureau of Mines and Geology.

[3] For the stratigraphy of Oregon see "The Salient Features of the Geology of Oregon," by W. D. Smith and E. L. Packard, *Jour. of Geol.*, vol. 27, No. 2, 1919.

senting various companies who have been through this field and who have of necessity had to take their information with them.

HISTORY OF DRILLING OPERATIONS.

As far as we have been able to ascertain the first well drilled for oil in the state of Oregon was in 1902. Since then approximately thirty wells have been drilled in the state in hopes of striking oil and not one has been successful. In fact, it can almost be said that not a barrel of oil has been obtained from a well in the state. At the present time, to our knowledge, there are four wells actually being drilled. Others are planned to start shortly and some have just been abandoned.

The latest venture is the most interesting of all that have come to our notice in this state. A firm, which by the way, is not unknown to California oil men from its operations at Half Moon Bay and from its claims to having discovered Signal Hill, is now puting down a well within a mile and a half of the State University on the property of the Eugene Bible University, an institution of the Campbellite Church. The promoter of this undertaking, an ordained preacher in this church, located the well site by the use of a "doodlebug." By means of this mysterious instrument, and with some reliance upon the confidence which his calling gives him, he has prevailed upon many citizens of Lane County to put their money into this venture. The geologists of the State University who had given out a signed statement, which had been requested by the local press, discussing the oil possibilities in this region, were attacked publicly by this promoter, who used as his only argument against the statements of the geologists that "persons who do not know the difference between a man and a monkey cannot be expected to know anything about oil!"

One of the latest projects being promoted in western Oregon is that of the oil shale near Ashland. There have been demonstrations of a small one-ton retort which appears to be effectual and much stock is being sold throughout the state.

TABLE I.

TENTATIVE TABLE OF STRATIGRAPHY OF WESTERN OREGON

PERIOD	FORMATION	TYPE LOCALITY	CALIFORNIA EQUIVALENT	LITHOLOGY	THICKNESS	TYPICAL FOSSILS	LIFE	STRUCTURE	IGNEOUS ACTIVITY	REMARKS
Recent	Terrace	Bandon Coast		Sands clays, gravel Marine sands, black magnetic beach sands Variegated sands	25'-50'		Fairly abundant	Weakly cemented deposits little disturbed	Volcanism in High Cascades	
Pleistocene				Loose sands and gravels & shell beds	100'-300'	Saxidomus gigantius Psephis stamineus	Abundant	Gentle dips	Volcanism in High Cascades	
Pliocene	Empire	Coos Bay Empire	Merced	Conglomerates, Sandstones, light colored shales	400'-500'	Pecten coosensis Chione securis etc Dendraster oregonensis	Mollusca abundant	Firmly cemented & gently Folded	POST EMPIRE intrusives & flows with tuffaceous deposits	Most of Western Oregon was above sea level and was heavily eroded Richland Oil Sands containing abundant leaves of deciduous trees
Miocene		NEWPORT	Temblor	Tuffaceous sandstones and shales	500-800	Pecten propatulus Cardium fossigerd Area devincta Leionucula? Yaquina Arius? Yaquinae orthocanis	Life not very abundant	Coastal deposits monoclinal sloping to west 10°-20°	Basaltic intrusives flows and tuffaceous deposits	Coastal deposits are dense and not of good character as petroleum reservoir Columbia lava (basalt) belongs in this group
Oligocene	Acila shales Astoria shales?	NEWPORT (May include part of Astoria shales)	Santa Lucia (?)	Dense dark gray shales very fine grained	2100'	ACILA GETTYSBURGENSIS ZONE Acila shumardi Fish scales Agassoma gravidum	Very rich in organic matter	Open gentle plunging anticlines and monoclinal in west coastal region. Gentle west dips	Pyroclastics	Acila shales near NEWPORT are petroleum odor when freshly fractured ASTORIA formation seems to be of same horizon as Acila shales, but only near NEWPORT were these shales found to be important as possible source of petroleum
	Yaquina	Yaquina	?	Lower 800' - Coarse grained sandstone buff colored with a slight showing of coal in lower part. Upper 1300' - Fine grained bluish colored gritty micaceous.	2300'	MOLOPHORUS LINCOLNENSIS ZONE (?) Siliqua angustata Acila, Thracia Phacoides, Spisula multima	Abundant mollusca life in some horizons	In coastal regions monoclinal dips to west	?	Equivalent to Astoria formation. Not of satisfactory character as source of petroleum products
	Toledo	Toledo	?	Tuffaceous sandstones and shales green gray in color when fresh	3000'	Thracia	Quite barren of evidence of life	Same as Yaquina	Pyroclastics	Very unsatisfactory as a possible source of petroleum products
Eocene	Coaledo	Coaledo Coos Bay	Ione (?)	Thinly bedded sandstones and shales of fresh & brackish water deposition, with number of coal beds near top	4000'	Ostrea Modiolus, Mytilus Brackish and fresh water Fossils in beds near coal measures	Some horizons rich in brackish water fossils, Plant remains from which coal was formed	Large gentle folds in COOS BAY region with some faulting and igneous intrusions	Probably the main intrusive masses such as MARY'S PEAK GRANITE MT and other Coast Range volcanic peaks were formed during CAMPO or early Oligocene time	The TYEE of FLORENCE and east of NEWPORT doubtless include the same horizon as The Coaledo of Coos Bay Not favorable as source of petroleum
	TYEE	Tyee Mt	Tejon (?)	Rather porous sandstone generally finely bedded with few separations of muddy gray shale The sandstone bluish gray & very micaceous	2500' Roseburg 5000'- Florence 8000'- Newport	Generally lacking in fossils Sandstone and shale often carry small fragments of carbonized wood Venericardia planicosta stearnsi? found in Tyee	Quite barren of life	Folded & faulted cut by volcanic intrusions	Basaltic intrusions and pyroclastics near crest of Coast Range Mountains	Contains nothing to produce commercial quantities of petroleum products
	Umpqua		Meganos	About 5000' of dark muddy sandstones and brown shale beds overlie the conglomerate. Base? conglomerate, largely made up of CRETACEOUS and metamorphic pebbles - 2,000'	5000'	Turritella inornata Turritella uvasana Foraminifera	All but a few horizons are barren of evidences of life	Folded & faulted	Basaltic intrusions	Excellent exposure at Rock Creek Dome
Cretaceous	Chico	Chico California	Chico	Conglomeratic sandstone & black shales		Trigonia evacuata Trigonia Fitchi	Fairly abundant			Several thousand feet of sediments deposited by transgressing sea Petroleum possibility
	Upper Myrtle	Riddle, Dem.	Horsetown (?)	Conglomerate sandstone and sandy shales	10000'	Trigonia angustifata Aucella crassicolla Aucella piochi	Lacking in much evidence of life, except plant remains	Folded faulted and somewhat altered by dynamic action	Granodiorite batholiths serpentine etc	Not of favorable character as possible source of oil and is badly folded and faulted
	Lower Myrtle	Myrtle Creek, Riddle	Knoxville							
Pre cretaceous metamorphics		Curry county	Metamorphics	Schists, cherts, greenstone, slaty shales & limestone	3000'	Radiolaria? Dictyomitra Conosphaera Ginkgo etc	Highly metamorphosed	Altered by excessive dynamic action.		Too badly changed by dynamic action to be of any value as producer of oil

Compiled by Warren D. Smith

FIG. 51.

The historical geology of western Oregon was outlined by Packard and the writer some years ago and, therefore, will not be repeated here. However, the writer will insert a more recent table of stratigraphy which embodies some of the data lately acquired in this region. The writer is indebted to Dr. E. L. Packard for some assistance in the preparation of this table, but for the table as a whole the writer alone is responsible. An earlier

table of stratigraphy, largely the work of Doctor Packard, will will be found in the joint article cited above.[4]

The essential facts brought out by the field work up to this time in western Oregon, may be summarized in a few words.

First, there should not be expected any petroliferous horizons in the Pre-Mesozoic formations, as these appear to be, wherever found, so disturbed and metamorphosed as to preclude any such possibility.

Second, in the Mesozoic, the Cretaceous, judging from California experience, offers the only hope and this depends upon several factors as yet more or less uncertain. Among these we should note the necessity of a considerable body of marine shales, abundance of organic remains in these shales, and suitable structures. These three essential prerequisites are by no means satisfied as far as our present data go.

Third, and finally, the Acila shales with intercalated sandstone beds in the Upper Oligocene or Lower Miocene seem to afford the most hopeful horizon from which to expect a yield of petroleum. Near Newport, Oregon, on the coast an unmistakable odor of petroleum was noted in the case of these shales, particularly those portions replete with minute fish scales, but the lack of suitable structures yet to be determined makes this only a possibility.

One of the most striking facts brought out by the two long detailed cross-sections of the Coast Range of Oregon, which the writer assisted in making (these are both published on a greatly reduced scale, unfortunately, in the bulletin cited above) is the comparative lack of suitable structures and the preponderance of basalt and diabase intrusions which cut such structures as do exist.

Any formation comparable to the diatomaceous shales of the Monterey Miocene of California seems to be entirely lacking in the western Oregon stratigraphic column, while in eastern Oregon the diatomaceous deposits are of fresh water origin.

Petroleum Seeps.—Contrary to reiterated claims, the writer

[4] *Loc. cit.*

knows personally of not a single genuine petroleum seep in Oregon. Examination of scores of so-called seeps has shown them to be accumulations of oxide of iron in marshy places, or nothing at all. A few have turned out to be frauds; one contained almost pure kerosene!

In western Lane County, near Florence on the Johnson Ranch, reliable witnesses have reported small amounts of oil and bituminous exudations in vugs in basalt dikes, but beyond this nothing promising is on record in western Oregon.

Were there any considerable petroleum accumulating in the sediments of western Oregon, there should be many seeps adjacent to the numerous basalt intrusions, but such apparently is not the case.

The excessive vegetation and heavy rainfall at certain seasons make the finding of seeps, did they exist, somewhat difficult.

PROSPECTIVE FIELDS IN WESTERN OREGON.

Astoria.—Below the city of Astoria, near the mouth of the Columbia River, attention has been directed for many years to strong gas seeps from the Astoria shales. The writer has made no particular study of this region, but according to some geologists the indications there are thought to be favorable, though others have had the contrary opinion. A well was sunk to some four thousand feet in depth in 1921 and eventually abandoned without securing a commercial supply of oil though it is maintained a strong showing of oil was obtained and that for various reasons the well was capped. The writer is of the opinion that while the well may have "made" some oil, it would not yield a commercial supply. According to Packard, there is little or no indication at this site of a suitable structure, the formations being concealed by alluvium.[4a]

Nehalem.—The Nehalem field lies about fifty miles south of Astoria on the coast. Recent studies in that region[5] show that there are possibly favorable structures in this region and a con-

[4a] Since this was written the writer has visited this locality and confirms Packard's observation.

[5] By Mr. Hubert Schenck, at present Associate in the University of California, and formerly graduate assistant in the University of Oregon.

siderable thickness of shales containing abundant organic matter. The supposed wax deposits of Nehalem have been shown by Professor Stafford, of the Department of Chemistry, University of Oregon, to be a true beeswax and not a paraffin residuum from petroleum. It was supposed that some ship plying between Mexico and the Philippines in the days of the Spanish galleons had run aground on the Oregon coast with a shipload of Philippine wax for use in making church candles; this suggestion is supported by the finding of pieces of driftwood near this deposit that resemble a common hardwood of the Philippines. There have been numerous stories about seabirds coming in from the open sea with a paraffin-like substance stuck to their feet, indicating that there might be some seeps off the coast. The writer has never seen anything which would substantiate these stories.

McMinnville and St. Paul.—These two places are not far from Salem, on the eastern side of the Coast Range. The writer made a study of the McMinnville area some years ago and felt at the time that, while there were many unfavorable features about that region, in view of the great interest in petroleum and the fuel shortage in the northwest (this was during war times), a test well, sunk by persons who could well afford the risk, might be justifiable. A well was put down a few hundred feet but abandoned without a test being made. This region was reported on many years ago by Mr. Chester Washburne. There are strong seeps of a gas with a high nitrogen content. However, it appears that it is a "dry" gas and so not coming from petroleum. Several small structures could be located in this region and as there appears to be little disturbance from igneous intrusions it offered some temptations to the wildcatter. To the east of McMinnville, at St. Paul some fairly deep wells have been sunk with negative results.

Newport.—Near Newport, Oregon, as has been stated above, there is a great thickness of the "acila shales," which are undoubtedly petroliferous. They are all monoclinal and it is the opinion of several geologists, including the field geologists of the firm of Eaton and Harrison, in which the writer concurs, that

providing suitable structures could be found in that general region there is some promise of obtaining commercial oil.

Waldport.—A few miles south of Newport, at Waldport, two wells were drilled,—one in the midst of the sand dunes north of Waldport and the other in highly inclined Tertiary shales to the south of the town. These wells have both been abandoned and with justification inasmuch as there was never any good reason for drilling in that region.

Eugene-Cottage Grove.—These two projects promise to have a sadder ending than those already considered since there are absolutely no favorable indications known to any of the geologists who have studied these particular localities. At Eugene there is, contrary to assertions which have been made, absolutely no "oil basin." The principal formation is the Eugene formation, and consists largely of tuffaceous shales and sandstones of Oligocene age in a monoclinal attitude, and intruded by basalt dikes and sills. The conditions at Cottage Grove are essentially the same. Derricks have been located on prominent hills in sight of the main streets of both towns and operations are carried on most vigorously on Sunday afternoons! The well near Eugene is down some eight or nine hundred feet, and has so far not "made" any oil or gas.

Oakland.—At Oakland, in Douglas county, a well some twelve hundred feet in depth has been sunk near the apex of a fairly sharp structure which was indicated by Diller many years ago in the Roseburg folio. Operations at this well have proceeded intermittently. The drilling was in Umpqua (Eocene) shales throughout. There was only a remote chance of this well being successful and that hinged upon the proximity of Cretaceous shales which outcrop in the southern part of this quadrangle.

Medford.—Near the city of Medford in southern Oregon is the locally well-known "Trigonia" well which gets its name, of course, from the typical genus of Cretaceous fossil bivalve in that region. When the writer last visited this well it was down twenty-two hundred feet and the cuttings showed coarse sandstone with considerable pyrite. Apparently it is close to the

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igneous basement. Showings of both gas and oil are claimed but the writer has not seen any, and a superficial examination showed no favorable structures; the general attitude of the formations here is monoclinal to the east.

Ashland.—Some sixteen miles northeast of Ashland, at an elevation of approximately forty-five hundred feet, on the east side of Grizzly Peak, the Hartman Oil Shale Syndicate is opening up and preparing to retort some shales which, it is claimed, yield a high percentage of petroleum, gasoline, and various by-products of commercial value. These shales are dark chocolate in color or are bleached to a cream color on exposed surfaces. They dip about fifteen degrees in a direction North thirteen degrees West. The shales are, in the upper portions of the outcrops, quite thinly laminated so as to merit the name of "paper shales," and are rich in leaves of deciduous trees. Above them is a rhyolite flow. The writer took large chunks from fresh cuts and placed them on open fires; in a short time oil bubbled out of the rock and strong fumes were emitted. Some of these shales strongly resemble carbonaceous shales associated with coal and in some of the test pits there are patches of a substance which strongly resembles coal; undoubtedly some of it is metamorphosed coal. It is claimed by those excavating, (which the writer could not check) that in the shaft nearby, (at that time full of water) nearly thirty-five feet of this oil shale was encountered and the bottom was not reached. The writer, however, saw enough in two or three open cuts to convince him that here is a promising deposit which, of course, would have to be fully drilled or test pitted before he would care to look favorably upon it. Furthermore, the economics of this prospect are of greater consequence than the quantity of shale or its chemical contents. The writer seriously questions whether this can be retorted economically in the face of a falling market for petroleum products. However, extensive operations are under way and several large retorts are being erected on the ground. Offices have been opened in Ashland, Eugene, and other cities, and considerable stock is being sold.

The writer ventures the suggestion that the oil in this shale originated from the profuse plant matter contained in it and that the rhyolite may have furnished heat enough to distil petroleum from these entombed organic remains. It is his opinion that what oil is present has been formed in place.

In closing the writer would like to emphasize again that it is dangerous to dogmatize. Any geologist who says positively there is no commercial oil in western Oregon lays himself open to some criticism. The facts do not justify either extreme, and so again it may be stated that from present indications western Oregon is a territory of *possible* but not probable petroleum reserve. It should be pointed out that few, if any, wells have so far been located on suitable structures and this may account for some of the failures to date. The writer is personally of the opinion that the prospects are by no means hopeless and that exploration by good companies may obtain petroleum.

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IRON SULPHIDES IN MAGNETIC BELTS NEAR THE CUYUNA RANGE.[1]

GEORGE A. THIEL.

INTRODUCTION.

THE so-called South Range of the Cuyuna Iron Range in Minnesota[2] contains numerous lenses of magnetite slates. They are banded or laminated rocks usually dark or grayish green in color and are generally referred to as amphibole-magnetite-slates.[3] Locally sufficient magnetite is present to produce strong magnetic deflections and for this reason numerous magnetic lines have been mapped and have served as guides for exploratory drilling for iron ore, and to a limited extent have also been useful in mapping the extent of the Deerwood iron formation. In the region southeast of Long Lake, however, strongly magnetic belts do not indicate the presence of the iron formation. Numerous magnetic lines that follow the general northeast-southwest strike of the magnetite slates are due to pyrrhotite in black graphitic slates and schists, and consequently may be confused with those caused by magnetite.

The writer is indebted to Mr. B. Magoffin of Deerwood, Minn. for access to samples of drill cores and exploration sheets of drilling; to Dr. W. H. Emmons, Dr. F. F. Grout and Dr. G. M. Schwartz of the Department of Geology at the University of Minnesota for helpful suggestions and criticisms.

GENERAL GEOLOGY OF THE LONG LAKE REGION.

Various types of rocks occur in the Long Lake region. Igneous rocks are exposed to the west and also to the southeast

[1] Published by permission of the Director of the Minnesota Geological Survey.

[2] *I.e.*, that portion of the range south of the Northern Pacific Railroad from Brainerd to Atkin.

[3] Harder, E. C., and Johnston, A. W., "The Geology of East Central Minnesota," Minn. Geol. Survey Bull. 15, 1918.

of Long Lake, and quartzite outcrops are found to the west of Dam Lake in T. 47 N., R. 25 W. Drilling has shown the presence of carbonaceous slates and gray schists to the southeast of Long Lake. The igneous rock outcrops are the most extensive and occur in sections 9 and 10, T. 46 N., R. 25 W. The rock is a medium to fine-grained diorite with a distinct diabasic texture. The magnetic belts in question lie to the south of the outcrops of diorite, but drilling has revealed the same dioritic rock intruded into the carbonaceous schists.

Winchell[4] states that the igneous rocks are the equivalent of the Keewatin greenstone of northern Minnesota and that the quartzite is a younger sediment. Van Hise and Leith,[5] however, believed the basic rocks are intrusives into the Upper Huronian metamorphosed rocks of this region, and consequently mapped them as Keweenawan. The latter drew their conclusion from the fact that numerous basic intrusives similar to those near Long Lake are found in many localities cutting the Deerwood formation supposedly of Upper Huronian age.

Structure.—The schists and slates of this region dip nearly vertically, although the regional dip is to the southeast. Local variations are observed due to the intrusion of the diabasic sills. The intensity of the folding is indicated by the number of minor folds, some of which are easily detected in the drill cores. The slates and schists that are partially replaced by sulphides are intensely crumpled and sheared and where the primary sulphide mineralization is finely disseminated through the schist, it follows the schistosity. Locally the sulphides are massive and only small areas of black graphitic schist remain.

The sulphides consist of pyrrhotite, pyrite, and marcasite. Pyrrhotite is especially abundant near the basic sills; some samples of drill cores consist of over fifty per cent sulphides with pyrrhotite predominating.

Pyrrhotite in the Lake Superior Region.—Pyrite and marcasite

[4] Winchell, N. H., "The Cuyuna Iron Range," ECON. GEOL., vol. 2, pp. 568, 1907.

[5] Van Hise, C. R., and Leith, C. K., "The Geology of the Lake Superior Region," U. S. Geol. Surv. Mono. 52, pl. 14, 1911.

are common constituents of the slates and graywackes of the Lake Superior region, but pyrrhotite is not frequently associated with them in sedimentary formations. On the east end of the Mesabi Range where the Keweenawan gabbro intrudes the Biwabik iron formation, pyrrhotite has been identified in drill cores.[7] Throughout the west portion of the range, however, it has not been observed in any of the pre-Cambrian sediments.

In the region of the Keweenawan rocks in northeastern Minnesota, pyrrhotite is associated with various phases of gabbro. In the area near Gabimichigami Lake it is associated with chalcopyrite and pentlandite in pegmatites that are composed of minerals characteristic of the gabbro.[8] North of Grand Marais it is also found in pegmatites derived from the gabbro.[9] In the massive gabbro, sulphides have been identified in numerous localities. They occur in small grains with irregular, rounded and angular outlines cutting or embaying any of the silicates and magnetite. These grains consist of a single sulphide or an intergrowth of pyrrhotite and chalcopyrite or of these two minerals and pentlandite. The chalcopyrite is always younger than the pyrrhotite and cuts it in narrow veinlets. Nebel states that the sulphides are of magmatic origin and belong to a late stage in the solidification of the gabbro. The presence of pyrrhotite in the Archean schists on the west side of Gabimichigami Lake is cited as further evidence in favor of the magmatic origin of the sulphide solutions.

On the Gunflint Range[10] pyrrhotite is present both in the iron formation and the sills intruding it. A twelve foot layer consisting of seven feet of iron formation and five feet of gabbro in the form of two sills averages 14 per cent. of pyrrhotite. Zapffe interprets the origin of the pyrrhotite as follows (p. 165):

[7] Grout, F. F., and Broderick, T. M., "The Magnetite Deposits of the Eastern Mesabi Range, Minnesota," Minn. Geol. Surv. Bull. 17, 1919.

[8] Nebel, M. L., ECON. GEOL., vol. 14, p. 367, 1919.

[9] Schwartz, G. M., "An Occurrence of Xonotlite in Minnesota," *Am. Min.*, vol. 9, 1924 (in press).

[10] Zapffe, C., "Effects of a Basic Igneous Intrusion on a Lake Superior Iron-bearing Formation," ECON. GEOL., vol. 7, p. 145, 1912.

. . . the iron-bearing formation was originally rich in pyrite and that due to regional metamorphism, heat supplied by the intrusive changed the pyrite present to pyrrhotite; sulphur fumes rose and in a small measure perhaps combined with some of the ferrous iron available higher up in the series and thus accounts for the presence of the small amount of the pyrrhotite in the contact phase of the intrusive mass above, though the heat of the mass itself no doubt also prevented to some extent the formation of pyrite.

Nebel, however, contends that the frequent association of chalcopyrite and pentlandite with pyrrhotite in the gabbro, together with a similar association in the Archean greenstone schists, and in the quartzite near the gabbro in the vicinity of Gabimichigami Lake, makes untenable any theory other than that postulating the derivation of the sulphides from the gabbro magma.

In Wisconsin pyrrhotite has been reported near Mountain where it occurs as a magmatic segregation in basic dikes.[11] No reference is made to its occurrence in the sediments of the iron-bearing series.

On the Michipicoten Range in Ontario, pyrrhotite and pyrite are found associated with black slates high in carbonaceous material. Coleman states that they have resulted from the reduction of sulphates by carbonaceous material which is commonly found in the phyllites of the iron formation. At these places the sulphate salts were thought to be more common than the carbonates and consequently numerous sulphides were precipitated in the graphitic beds.[12] No mention is made of the origin of the mineralizing solutions.

At the Northpines pyrite mine[13] at the east end of Vermillion Lake, Ontario, pyrite is associated with pyrrhotite, magnetite, chalcopyrite and sphalerite. Pyrite is by far the most abundant sulphide in the ore body. The pyrrhotite is present as minute

[11] Bagg, R. M., "The Discovery of Pyrrhotite in Wisconsin," ECON. GEOL., vol. 8, pp. 369, 1913.

[12] Coleman and Willmott, "The Michipicoten Iron Range," Ont. Bur. Mines, 11th Rpt., pp. 152.

[13] Hanson, George, "Some Canadian Occurrences of Pyritic Deposits in Metamorphic Rocks," ECON. GEOL., vol. 15, pp. 590, 1920.

grains in pyrite and as irregular branching areas between pyrite grains. Pyrite was the first mineral to crystallize. Magnetite appears to be later than the pyrite but it is probable that pyrite continued to be deposited after all of the magnetite had been formed. Pyrrhotite is clearly later than these two minerals.

PARAGENESIS OF THE IRON SULPHIDES OF THE LONG LAKE REGION.

Pyrrhotite.—The primary mineralization of the schists and slates in the Long Lake region involved only one sulphide, pyrrhotite. Analyses of samples give negative results for such metals as copper and nickel that are frequently associated with pyrrhotite. It occurs as (1) replacements in the schist, (2) as thin lamellae following the schistosity of the rock, and (3) as minute veinlets cutting across the schistose structures. The replacements favor bands of schist that are highly carbonaceous. In them the pyrrhotite replaces quartz, carbonates, and needles of fibrous amphiboles. Where the sulphide is finely disseminated, the minute grains are arranged in parallel rows that follow the schistosity and in some cases develop a texture similar to a "lit-par-lit" injection. All of the specimens examined contain the pyrrhotite in a massive form. A few grains possess sub-hedral crystal outlines, but no euhedral crystals were observed.

Pyrite.—Pyrite is clearly later than the pyrrhotite and both in the igneous rock and in the slate it is present as large euhedral crystals that show no definite orientation or as stringers, veinlets and replacements of massive pyrite that cut all of the other minerals. It replaces quartz, carbonates and pyrrhotite. Some secondary pyrite enters along the contact of pyrrhotite grains with gangue. In the same section pyrite is also seen replacing euhedral quartz grains.

Marcasite.—The marcasite was identified by its pale yellow color and concentric structure. It is confined to veinlets and concentric replacements in the other sulphides and in the gangue. The veinlets fill fractures that cross the schistosity of the rock, and some are seen healing fractures in euhedral pyrite crystals.

Many of the veins composed of quartz and marcasite are conspicuously banded, with quartz filling the central portion of the vein. Where the replacement began along the contact of pyrrhotite with gangue, the sulphide is more easily replaced and the concentric marcasite retains a straight contact with the gangue but projects deeply into the pyrrhotite. (See Fig. 52.) The

FIG. 52. Marcasite (*M*) replacing pyrrhotite (etched black) along contact with gangue (*G*). ×60.

presence of such concentrically banded marcasite is further evidence of the secondary origin of the pyrite and marcasite as such textures are characteristic of cold water deposition.

RELATIONS OF THE SULPHIDES IN THE LONG LAKE REGION.

The absence of primary pyrite associated with the pyrrhotite in the Long Lake region indicates that the pyrrhotite was formed under conditions of high temperature. If pyrite was present it may have been dissociated and recrystallized as pyrrhotite. There is no direct evidence that such transformation takes place during deposition at high temperatures, but laboratory experiments indicate that the reaction between pyrite and pyrrhotite is a re-

versible one.[14] Certain phenomena near contacts of igneous intrusives in shale suggest such a reaction. Lindgren states that pyrrhotite is almost always present in contact metamorphic shales that show sulphide mineralization and in such shales pyrite develops normally at some distance from the contact, whereas close to it pyrrhotite is universally present, and contains little if any pyrite. In the Long Lake region the pyrrhotite was undoubtedly derived from the basic magmas that intrude the schists. If pyrite was present in the schist at the time of intrusion, it was entirely recrystallized, as no traces of pyrite earlier than pyrrhotite were observed in the specimens examined. Pyrite is present in the diabase, but it is clearly a secondary mineral.

SUMMARY.

1. Magnetic lines cannot be relied upon in mapping the extent of the Cuyuna amphibole-magnetite-slates in the region of Dam Lake. In this area, diabasic intrusives have developed contact zones of pyrrhotite that are highly magnetic.

2. Analyses of samples give negative results for such metals as nickel and copper that are frequently associated with pyrrhotite deposits.

3. The order of paragenesis of the sulphides is pyrrhotite, pyrite and marcasite.

4. The sulphide solutions were derived from the basic igneous rocks and deposited pyrrhotite under conditions of high temperature near the dikes and sills. Pyrite and marcasite were deposited later, presumably by colder solutions. Some of the latter minerals replace pyrrhotite and may represent an alteration of that mineral.

[14] Allen, E. T., Crensham, J. L., and Johnston, J., "The Mineral Sulphides of Iron," *Am. Jour. Sci.*, 4th Ser., vol. 33, pp. 169.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.

EDITORIAL

WHAT IS AN ECONOMIC GEOLOGIST?

ANY reader can answer the question, "What is an economic geologist?," immediately with some such definition as "A geologist who brings the aid of his science to the solution of economic problems." This is a broad definition, however, and immediately suggests that there is further specialization even in such a group of specialists.

Any member of a state or federal survey who prepares a report on mineral resources or a paleontologist or student of mountain building forces who contributes of his highly specialized knowledge, even indirectly, to the solution of mining problems becomes for the moment, and rightly so, an economic geologist.

Our general conception of economic geology, however, is something more specific. We usually think of the groups of men, both in mining and petroleum geology, who are chiefly devoting their energies to the application of the principles of their science in the finding and producing of mineral wealth on a basis more profitable to themselves or their employers than can be achieved without the use of applied geology. The question of relative profit, immediate or ultimate, is all important and the geologists of this group, who might perhaps better be called commercial geologists, are successful in direct proportion to the amount which their work contributes to this profit.

Geology is the kit of tools with which the commercial geologist works rather than the mistress whom he serves. Manifestly, he who is best equipped with tools, other things being equal, should be the most capable workman, but it is seldom that other things are equal. I have known a Mexican carpenter who, with the crudest of tools, was a skilled cabinet-maker, and I have known other carpenters who, in possession of every tool desired, were mere wood-butchers.

The point I wish to emphasize is that the desire and ability to

make timely and profitable application of geologic knowledge are as important in the economic geologist as competence in geological science itself. Some of the ablest and most successful petroleum geologists I have known, could not claim to high rank as geologists alone. On the other hand, some of the most competent geologists working in petroleum geology to-day are not extremely successful petroleum geologists. I have in mind a certain petroleum geologist. He is not one of the best oil men in the country nor is he one of the best geologists but he is certainly one of the best petroleum geologists. He excels in his ability to make profitable use of geology. I do not suggest these cases as establishing a rule but in support of the argument for the importance of sense of value in application.

It is difficult if not impossible to define satisfactorily and generally this sense of value. It involves many practical and common sense considerations. In petroleum geology, so largely a matter of prospecting for new deposits, I should say that one of the important components is a constant consciousness of the geologist of the extent to which he is dealing in fact and the extent to which he is dealing in theory,—an ability to gauge, so far as possible, the value of his own conclusions, and to select for practical operations, those prospects involving the least risks. The petroleum geologist is not concerned with testing every prospect where it is scientifically possible for oil to occur but rather in finding the best prospects—those involving the least risk. One of his most important functions in his company is to reduce the hazards commonly incident to the business.

Upon entering commercial geology, some fifteen years ago, the strictest injunction which I received from my chief, himself an eminent and capable scientist as well as a practical petroleum geologist, was, "less geology and more common sense." I take it that this admonition was not literally against geology but rather against basing operations upon highly theoretical and speculative conclusions. It is good advice.

E. DEGOLYER.

DISCUSSION AND INFORMAL COMMUNICATIONS

THE ORIGIN OF VEINS OF FIBROUS MINERALS.

Sir: Fibrous minerals most commonly occur forming veins in which the fibers are all parallel and run transverse to the strike of the veins. The fibrous varieties of some minerals occur only in such veins. The origin of chrysotile veins has been discussed by many writers for they are of greatest economic importance; little attention has been given to the origin of fibrous veins of other minerals although they all have certain structural peculiarities which strongly suggest that they have been formed in the same way. Most theories advanced to explain the origin of fibrous veins have been limited to chrysotile and would not be applicable to veins of other minerals. It is, of course, possible that fibrous veins have been formed in several different ways, but, at least until this has been proved, a theory that is applicable to all fibrous veins is more plausible.

The many theories advanced to explain the origin of fibrous veins may be grouped in three classes, namely: (1) they were deposited in open fissures; (2) they were formed at the expense of the walls by recrystallization *in situ* or by replacement; and (3) the veins, in growing, displaced the wall rock.

1. The hypothesis that fibrous veins have been formed in pre-existing fissures is, in most cases, obviously untrue and seems to have been generally abandoned by recent writers. Some of the principal objections to it are: Fibrous veins extend horizontally for distances of 150 feet or more especially in sedimentary rock strata. They sometimes ramify in all directions and make up over 10 *per cent.* of the entire rock mass. Isolated inclusions of wall rock are common in all kinds of fibrous veins. When

fibrous minerals are found growing in open spaces the fibers usually curve in different directions and are often more or less tangled; but, in veins, the fibers are always parallel. If the veins were formed in an open fissure there should be a suture line near the center. While many fibrous veins have a central parting it is usually very irregular and is marked by numerous inclusions of the wall rock; in many veins the fibers extend from wall to wall without a break and in others there are several partings. Fibrous veins are commonly lenticular and short in proportion to their width; often the lenses are isolated in such a way as to preclude formation of the space by external force. The formation of some chrysotile veins has apparently coincided with the serpentinization of the inclosing rock, but, since the formation of serpentine from anhydrous minerals is accompanied by increase in volume, it would be impossible for fissures to remain open during the process.

2. The theory that chrysotile veins represent portions of the serpentine which have recrystallized *in situ* has been advocated by Dresser [1] and Graham [2] for the Quebec deposits; and the replacement theory has recently been applied by Professor Bateman,[3] with certain modifications, to the chrysotile of Sierra Ancha, Arizona.

The serpentine and chrysotile of Sierra Ancha have been formed as a result of the action of diabase, or of hot solutions derived from the diabase, on magnesian limestone. Similar deposits have been found at several other places in Arizona, and in the Carolina district of the Transvaal, South Africa,[4] so that the origin of this type of chrysotile deposit is of more than local interest. Bateman [5] states that "a study of thin sections shows

[1] Dresser, J. A., "Preliminary Report on the Serpentine and Associated Rocks of Southern Quebec," Canada Department of Mines, Geol. Surv., Memoir No. 22.

[2] Graham, R. P. D., "Origin of Massive Serpentine and Chrysotile-Asbestos, Black Lake—Thetford Area, Quebec," ECON. GEOL., vol. 12, 1917, pp. 154–202.

[3] Bateman, A. M., "An Arizona Asbestos Deposit," ECON. GEOL., vol. 18, 1923, pp. 663–683.

[4] Hall, A. L., "On the Mode of Occurrence and Distribution of Asbestos in the Transvaal," *Trans. Geol. Soc. S. Africa*, vol. 21, 1918, pp. 4–7 and 25–29.

[5] *Loc. cit.*, p. 676.

that the chrysotile has grown by the replacement of serpentine, and to a lesser extent, of carbonate." In a previous paper I suggested that "where chrysotile veins occur in limestone, as they do in Arizona, it is possible for some replacement of the inclosing rock to take place";[6] but, a further examination of specimens from the Arizona districts together with a study of the descriptions given by Bateman and others has not convinced me that replacement is the only factor involved in the formation of the chrysotile veins nor that it is even the most important factor.

3. The peculiar structure of cross-fiber veins has been attributed by me to the mechanical limitation of crystal growth through addition of new material in only one direction, the material for growth being supplied through small, closely spaced openings in the walls, which have been pushed apart by the growing veins.[7] This theory is applicable to all kinds of cross-fiber veins; in veins of the asbestiform minerals the fibrous structure is accentuated by a normal prismatic habit and cleavage. The theory was based, in part, on a series of experiments in which fibrous veins were produced in the laboratory where their manner of growth and the development of their structural peculiarities could be kept under constant observation. The value of such experimental evidence has been questioned, but, it would seem that in the solution of such complicated problems as those relating to the origin of veins, no method of attack should be neglected, and evidence derived from experiment is as pertinent as any other so long as it is not contradicted by observational evidence from natural veins.

In the laboratory experiments several different salts were used including some which separate from solution with increase and some with decrease in volume. They belonged to different systems of crystallization, and none developed slender acicular forms under normal conditions of crystal growth; the fibrous forms obtained being due to the fact that material for growth was avail-

[6] Taber, Stephen, "The Genesis of Asbestos and Asbestiform Minerals," *Trans. Amer. Inst. Min. Engrs.*, vol. 57, 1917, p. 73.

[7] Taber, Stephen, "The Origin of Veins of the Asbestiform Minerals," *Proc. Nat. Acad. Sci.*, vol. 2, 1916, pp. 659–664.

able in one direction only. These fibrous crystals were relatively unstable, and when placed in solutions either dissolved or developed into crystals of normal habit. The fibrous varieties of many minerals are found only under conditions which are essentially similar to those used in the laboratory production of fibrous crystals, and in many instances there is positive evidence that the fibrous minerals have developed in the same way.

The walls of fibrous veins are occasionally irregular, and then it may be seen that convexities on one wall are matched by corresponding concavities in the other. This may be observed even when the wall rock consists largely of the same material as that forming the vein, as where calcite veins occur in limestone or chrysotile veins in serpentine. A good illustration is furnished by the chrysotile vein cutting serpentine (shown in Fig. 53) from

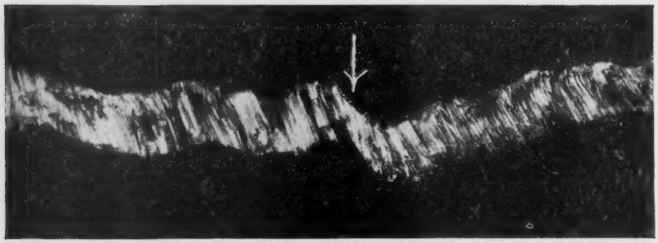

FIG. 53. Chrysotile vein in serpentine. Convexities of one wall match opposite concavities. Fibers extend in the direction the walls have been displaced. Vein is narrowest where walls are most nearly parallel to direction of displacement.

the deposits near Lowell, Vermont. The surface photographed is essentially a plane and was placed normal to the axis of the camera lens. It should be noted that the vein is narrowest in the sharp bend (indicated by an arrow) where the walls are, locally, most nearly parallel to the direction in which they have been displaced. Obviously such veins have not been formed by replacement or recrystallization *in situ*.

Fibrous veins are often highly lenticular in form, but the walls

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of these veins occasionally show minor irregularities, such as those described above, and other evidence indicating that they have been displaced instead of destroyed. The displacement takes place slowly permitting the adjustment of stresses by recrystallization in the same way that slabs of marble are deformed by small forces acting through a long period of time. The Tasmanian chrysotile veins shown in Fig. 54 illustrate the warping of

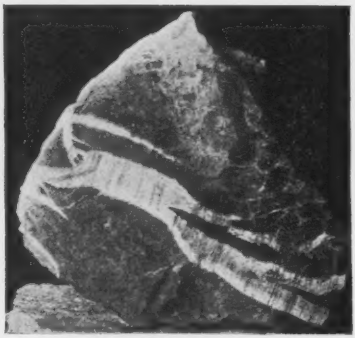

FIG. 54. Chrysotile veins from Tasmania. *After W. H. Twelvetrees.*

country rock by vein growth. If the chrysotile were removed the walls and angular inclusions, except for the minor bending, would fit closely together. These phenomena may also be observed in veins of other fibrous minerals such as calcite and gypsum.

Fibrous veins have sharply defined walls from which they are rather easily separated, this ease of separation being especially characteristic of chrysotile and crocidolite veins. (See Figs. 55 and 56.) On the other hand veins known to be formed by replacement are characterized by irregularity in width and lack of definite boundaries. Bateman [8] describes little veinlets of chrysotile in areas of serpentine which are revealed in thin sections under the microscope, and states that the margins of these microscopic veinlets have a frayed and jagged appearance due to re-

[8] *Loc. cit.*, pp. 676–677.

placement. Specimens of the larger veins, from the Arizona deposits, examined by me, show the sharply defined walls charac-

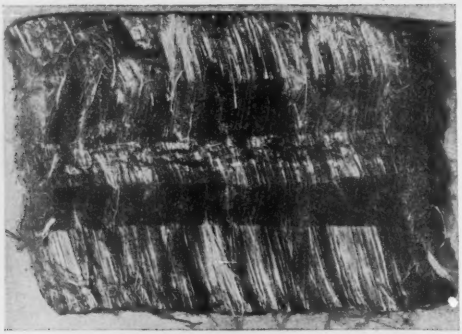

FIG. 55. Chrysotile vein from Thetford, Canada, with abrupt bends in fibers arranged symmetrically with respect to the central parting, which is marked by small inclusions.

teristic of fibrous veins of other districts. Some of the Arizona veins persist for many feet with little variation in width.

As proof that the larger chrysotile veins have replaced their

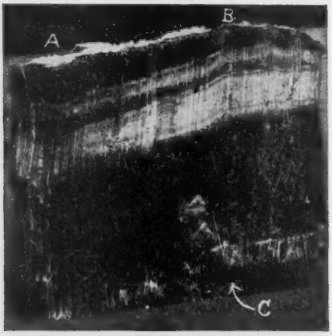

FIG. 56. Chrysotile vein from deposits near Globe, Arizona. Banding is due to slight bends in the fibers. Irregularities along the wall such as concavity at "A" and convexity at "B" are reproduced in the bands. Large inclusion at "C."

walls instead of displacing them, Bateman describes three parallel veins totaling 6½ inches of chrysotile, which have caused no bulge in the bedding-planes of the inclosing rock;[9] but, accord-

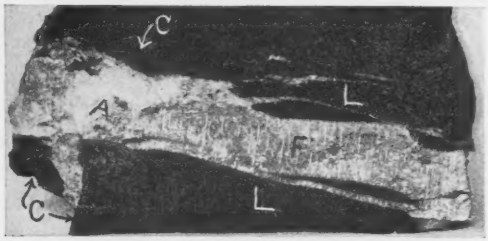

FIG. 57. Calcite vein from Union Springs, N. Y. It is fibrous (*F*) where the walls are limestone (*L*) and coarsely crystalline (*A*) where the walls are chert.

ing to his detailed description and diagram very little if any distortion should be expected.

Two of the veins, having a combined thickness of 2½ inches, extend beyond the area under consideration and therefore could cause no local distortion. The third vein having a maximum width of 4 inches is, according to the diagram, nearly 8 feet long, pinching out gradually at both ends. Now, assuming that all of the vein material came from some source outside of the immediate inclosing rock, and this I have never suggested for fibrous veins, the maximum displacement of the wall rock would be about two inches on each side, gradually decreasing to zero at the ends of the vein. The slight distortion of the bedding-planes caused in this way would be very difficult to observe. But, I believe that the material for vein growth was derived chiefly from the inclosing rock, and there has evidently been considerable recrystallization of the minerals in that rock. These factors would further reduce the distortion of bedding-planes. In previous papers I have attributed the formation of fibrous veins to lateral secretion, and have called attention to the fact that "Cross-fiber

[9] *Loc. cit.*, pp. 677–678.

veins are composed essentially of a single mineral, which is also, usually, an important constituent and often the dominant mineral in the wall rock. . . . In rare instances the vein mineral is not found in the wall rock, but in such cases it is a secondary mineral which has evidently been derived from minerals that are present in the wall rock." [10] In one sense this may be interpreted as recrystallization, but it is not recrystallization *in situ*. If the bedding-planes were not disturbed by the serpentinization of the limestone there is no ground for assuming that they would be greatly disturbed by the growth of lateral secretion veins. In certain crocidolite deposits, however, where the veins show much more abrupt variations in width, minor distortion of bedding-planes has been observed.[11]

Professor Bastin [12] argues that at Thetford, Quebec, where the serpentine is penetrated by a ramifying mass of veins, growth by displacement of the walls would manifest itself in structural deformations of bordering formations. But, the only expansion postulated in my theory of the origin of the Thetford chrysotile veins is that involved in the hydration of the peridotite to form serpentine. The chrysotile veins represent portions of the serpentine taken into solution and transported chiefly by diffusion through the subcapillary pores of the rock to the walls of the growing veins.

In fibrous veins grown in the laboratory the crystals are invariably elongated in the direction in which the walls move as they are pushed apart. If a vein is straight and the walls move directly apart, the fibers are normal to the walls, but, if the walls have also a lateral displacement the fibers grow in the direction of the resultant motion. Therefore in crooked veins the fibers may be normal to the walls at one place and oblique at others. In natural veins of fibrous minerals having irregular walls that match, as in the chrysotile vein shown in Fig. 53, it may be seen that the fibers always extend in the direction in which the walls

[10] Taber, Stephen, "The Mechanics of Vein Formation," *Trans. Amer. Inst. Min. Engrs.*, vol. 61, 1919, p. 25.

[11] Hall, A. L., *op. cit.*, pp. 19–21.

[12] Discussion of Professor Bateman's paper. ECON. GEOL., vol. 18, 1923, p. 671.

have been displaced. If fibrous veins were formed by replacement or recrystallization *in situ* the fibers, presumably, would be oriented in diverse directions.

Occasionally, during the growth of laboratory veins a branch vein would begin to develop, thus giving the walls of the older vein a lateral motion and causing a bend to appear in the growing fibers. Similar bends are common in veins of all kinds of fibrous minerals including those that are not flexible, such as calcite and quartz. The fibers of the chrysotile vein from Thetford, Canada, shown in Fig. 55, record two sudden changes in the relative movement of the walls. Since the rate of growth, in this instance was practically uniform on both sides of the vein the bends are symmetrical with respect to the central parting. Sharp bends and curves in the fibers of veins can not be explained by an hypothesis of vein formation through replacement or recrystallization *in situ,* for if growth is at the expense of the walls the fibers would continue to grow in the direction in which they had started, growth being controlled by the forces of surface tension and molecular orientation, and by the forces resisting growth.

Curved and sharply bent fibers are most frequent where veins branch and ramify in all directions; they are rarer where the veins are mostly parallel as in the Arizona chrysotile deposits. Even though the fibers are but slightly bent the flexures are easily recognized, for the veins have a banded appearance due to the unequal reflection of light where the fibers run in different directions. If a vein wall is irregular the light-bands show the same irregularities as the adjacent wall from which the fibers have grown. This is illustrated by the specimen of chrysotile (see Fig. 56) from the Ash Creek deposits near Globe, Arizona; these deposits being of the same type as those at Sierra Ancha and unquestionably formed in the same way. The top of the specimen was dusted with powdered chalk so that irregularities in the wall could be more readily recognized in the photograph. The concavity at "*A*," the convexity at "*B*," and other minor irregularities are faithfully reproduced by the light-bands. If

the vein was formed at the expense of its walls the irregularities of the present wall could have had no effect on the bands.

There are also bends in the fibers near the opposite wall, but they do not show up well in the photograph. The vein has several partings, all near the lower wall of the specimen, and inclusions of the wall rock such as that at *"C"* also occur. The central parting is much nearer the wall on which the specimen rests, thus indicating that the fibers grew more rapidly from the other wall. Unequal growth from the opposing walls of chrysotile veins seems to be more common in deposits formed in bedded rocks than in those formed in altered peridotites, but additional evidence is needed on this point.

Fibrous veins grown in the laboratory commonly have a central parting caused by the growth of fibers from both walls of a fracture. Absence of a parting is in some cases due to growth at both ends of fibers when the formation of the fracture and the beginning of vein growth are simultaneous; in other instances the absence is due to the development of the fracture in a direction such as to cut one side off from solutions furnishing material for growth. Partings may also be caused by a pause in the process of vein growth or by a slight displacement of a wall relative to the vein. Similar partings are common in veins of fibrous minerals of all kinds, and likewise they are often entirely absent, especially from small isolated lenticular veins. In some veins the partings are very irregular, because of the more rapid growth of certain groups of fibers that are more favorably situated to receive additions of new material. The theories of replacement and of recrystallization *in situ* do not account for the vagaries of partings.

Some fibrous veins show color banding parallel to the walls due to slight changes in the composition of the vein forming solutions, and these color bands may be displaced and made irregular in the same way as with partings.

Inclusions of wall material are abundant along the central partings of laboratory veins, and occasionally vein matter crystallizing along a line of weakness close to a vein wall gradually

separates a fragment from the wall and includes it in the growing vein. Similar inclusions are common in all types of fibrous veins found in rocks. Numerous small inclusions of chromite and massive serpentine may be seen near the center of the vein shown in Fig. 55, and larger inclusions of wall rock are shown in Figs. 54, 56, and 57. It is often possible to find niches in the adjacent walls into which large inclusions would exactly fit. Neither replacement nor recrystallization *in situ* furnish an explanation for such inclusions. Inclusions are, as a rule, more abundant near the central parting than near the walls; the reverse should be true if the veins have been formed at the expense of their walls.

In veins of fibrous minerals, such as calcite, which do not under normal crystallization develop acicular forms, the diameter of the fibers varies with the texture of the wall rock. Calcite veins which are finely fibrous where the walls are of fine grained limestone become coarsely crystalline where they cut through chert nodules (see Fig. 57), because here the vein-forming material has had to diffuse between the chert walls instead of through them. Minerals having a normal prismatic habit and cleavage are probably likewise modified, though to a lesser degree. This possibly explains the variation in texture and flexibility of fibers in some chrysotile veins.

The evidence outlined above tends to substantiate the view that fibrous veins have made room for themselves by displacing their walls rather than by destroying them. While some evidence of replacement may be observed in the wall rock of certain veins, such as those of Sierra Ancha, I am convinced that this process has played a very minor part in the formation of the veins.

Referring to the mechanism of replacement, Bateman states that "if it could be established experimentally [that pressure resulting from the growth of the replacing mineral could bring about the solution of the mineral being replaced] it would . . . elucidate the whole problem of replacement."[13] This method of

[13] Bateman, A. M., *loc. cit.*, p. 679.

replacement I have discussed at some length in a previous paper.[14] and I believe that it has been proved both experimentally and from observation. Experimentally the problem offers certain difficulties unless it is simplified by considering each component factor separately, and this is what I have done. It has been proved (1) that a crystal in growing can exert great pressure; (2) that pressure increases the solubility of most substances; and (3) that two substances can diffuse in opposite directions through a thin film of solution separating two solids. In one experiment two crystals of the same salt were placed under pressure in a concentrated solution; the one under the greater pressure went into solution while the crystal under less pressure grew at the expense of the other.

It has been suggested that the veins of fibrous calcite found at Sierra Ancha are pseudomorphous after chrysotile, but in view of the evidence adduced by Bateman it would be more logical to consider the chrysotile as pseudomorphous after the fibrous calcite. Veins of fibrous calcite are not uncommon in limestones and calcareous shales, and they have all of the structural characteristics of chrysotile veins except flexibility of the fibers. The theory of vein formation here advocated is applicable to both, and also to the many others fibrous minerals having a similar mode of occurrence.

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X-RAY DETERMINATION OF MINERALS.

Sir: For the past four years the X-ray method of examination and study of crystalline powders, perfected and described by Hull of the General Electric Company, has been in almost constant use in the Department of Geology of the University of Wisconsin, serving not only in connection with work in geology and mineralogy but also solving numerous problems for investigators

[14] Taber, Stephen, "The Mechanics of Vein Formation," *Trans. Amer. Inst. Min. Engrs.*, vol. 61, 1919, pp. 27–33.

in chemistry, metallurgy, and in other lines where questions involving the nature of sub-microscopic crystalline substances arose. We are consequently very much interested in the article by Paul F. Kerr on "The Determination of Opaque Minerals by X-ray Diffraction Patterns" in the January-February, 1924, number of your journal.

The demonstrated usefulness of this method of study in connection with geological and mineralogical problems makes it certain that a large literature will develop along this line. The application of this method of mineral analysis has barely begun, and it is very desirable that all the data accumulated be presented in such form that results can be compared and much duplication avoided. Two diffraction patterns can be directly compared only when they have been made with radiations of the same wavelength and with film quadrants of equal radii. The spacing of the lines on the diffaction pattern can, however, be given in terms of the distances between the atomic planes producing them, and this method of expression reduces all patterns to comparable figures. In addition to the spacing of the lines, the intensity is of importance. In the apparatus which we are using[1] each film cassette contains a series of overlapping metallic leaves built up as a "stairway," which is registered on the film as a scale showing the relative intensities of X-rays that have penetrated different thicknesses of the metal. A rough measurement of the intensity of the lines in the diffraction pattern can be made by comparing them with this scale. The diagrams and halftones of diffraction patterns of ore minerals illustrating Mr. Kerr's paper are of interest, but it is unfortunate that the data are not presented in a form which can be used and checked by others working along similar lines.

In the article referred to, the observation that "franklinite and magnetite specimens gave identical patterns," does not correspond with the results obtained in our laboratory. The following table

[1] X-ray Diffraction Apparatus manufactured by the General Electric Company, and described by William P. Davey in the *General Electric Review* of September, 1922.

shows the patterns obtained by the writers from magnetite and franklinite. The spacing is given by the distances, expressed in Angstrom units, between the corresponding atomic planes, and the intensity of each line is indicated by a symbol. "H" denotes a heavy line, "M" one of moderate intensity, and "L" a light line. Five specimens of franklinite were tested, and though the streak of these varied considerably, the patterns were not noticeably different. As a final check, magnetite and franklinite were photographed together, each set of lines occupying one half of the film. This film shows the lines definitely offset.

FRANKLINITE.		MAGNETITE.	
Angstroms.	Intensity.	Angstroms.	Intensity.
3.040	L	3.010	L
2.940	L	2.910	L
2.580	L	2.560	M
2.510	H	2.490	H
2.085	L	2.070	M
1.710	L	1.700	L
1.610	H	1.600	H
1.480	H	1.470	H
1.324	L	1.315	L
1.278	M	1.270	M
1.124	L	1.118	L
1.091	M	1.085	M
1.050	L	1.044	L
.970	M	.965	M
.881	L	.877	L
.858	L	.854	L
.812	L	.808	L
.758	L	.754	L
.676	L	.672	L
.666	L	.662	L
.644	L	.640	L
.591	L	.587	L
.564	L	.560	L

The pattern obtained from an X-ray analysis is determined by the kind and arrangement of the atoms that make up the mineral, and it is clear that absolutely identical patterns can mean only that the substances analyzed contain the same kinds of atoms with the same arrangement, that is, have the same mineralogical com-

position. Theoretically the substitution of manganese for ferrous iron in any fixed space lattice would involve differences in the intensity of the lines so slight as to be unnoticed, although even in such a case it cannot be said that the patterns are identical, but merely that the apparatus used does not indicate a difference. However, such a discussion is purely hypothetical, and the experience of the writers has been that with the apparatus used the effect of the two factors, the kind of atom and the structure of the atomic lattice, results in patterns which are noticeably different for different minerals.

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REVIEWS

Geologic Structures. By BAILEY WILLIS. McGraw-Hill Book Company, New York, 1923. 295 pages, 121 text figures, 10 plates.

Mr. Willis states in his preface that "The purpose of this book is to describe geologic structures and to apply the principles of mechanics to their interpretation." Accordingly the first chapters are devoted largely to definitions and descriptions of folds, faults, joints, and cleavage, and this discussion is followed by a chapter on mechanics of rock deformation. Some practical applications are then considered in a chapter on field methods, and Robin Willis has contributed a final section entitled "Graphic methods and practical problems." The largest of three appendices is used for descriptions of model folds, the illustrations of which are taken from Mr. Willis's well-known paper "Mechanics of Appalachian Structure."

The author writes from a wealth of experience, an advantage reflected particularly in certain portions of the book. His chapter on field methods is delightful and instructive reading. It is written attractively and simply—as he says, "in English rather than in Geology"—and is flavored with hints of personal reminiscence. The discussion is general rather than specific, for the writer seeks to emphasize fundamentals. Some readers may feel that he shows too much contempt for instrumental methods; but no doubt he is justified by his purpose to stress the importance of acquiring that "geological sense" without which the field worker can never succeed.

In other portions of the book the treatment appears to be less successful. It is doubtful whether a subject like structural geology can properly be served up in the same form for "the untechnical reader as well as for the special student." In some parts the exposition is very elementary, in other parts it seems advanced. Certainly special students will not regard the book as a comprehensive treatise, and many will not agree with some notions of mechanics that are *proposed*. For example, Mr. Willis considers it an established principle that intersecting shear planes developed by compression will always present an obtuse angle toward the compressive force. He emphasizes more than once the theoretical shear angle of 45°, and apparently recognizes as the only modifying factor the varying tendency of rock to spread sidewise, increasing the angle of intersection beyond 90°. In this conclusion he seems incon-

sistent, for elsewhere (p. 91) he indorses the discussion of low-angle faulting by Chamberlin and Miller, although these workers emphasize the effect of a component normal to the shear plane, operating to decrease the theoretical angle materially. The tendency of brittle substances to shear at low angles has long been recognized in engineering mechanics and is discussed in many good text books. Evidently the process of rock shearing is influenced by many factors, some of them not well understood, and the subject cannot be disposed of by any simple analysis.

The author is to be commended for his obvious intent to use the simplest language possible and to avoid involved statements. The reviewer does not feel, however, that all of the sentences are entirely lucid, and in some places it appears the wrong word has been chosen. In one paragraph (p. 64) the writer speaks more than once of a joint nearly *vertical* to a fault plane, although the joint represented in the figure is by no means vertical. Presumably the word *perpendicular,* in the geometrical sense, is intended.

A feature of the book is the use of sketches and line drawings to the exclusion of photographs. The discussion of striae and other marks on fault surfaces is more comprehensive than the reviewer has seen elsewhere.

C. R. LONGWELL.

Sur la détermination des minéraux par l'examen microscopique de leur trace laissé sur un corps dur. GAUBERT, M. P., Comptes Rendues, vol. 177, pp. 960–2 (Nov.) 1923.

New methods of examination and determination of minerals, particularly when intimately mixed, have developed rapidly in recent years but the possibilities have not been exhausted as this investigation has shown.

The streak of a mineral on a porcelain plate has long been used as a diagnostic, but a new application is made. A glass slide which has been roughened with emery is used in order to permit an examination under the microscope. Transparency is obtained by covering the streak with oil having an index near that of glass. A cover glass is, of course, put on the oil. The particles composing the streak are said to be well suited to examination under the microscope, and the following points regarding the mineral particles may be observed:

1. *Their Form.*—Evidence of malleability of the substance is shown by the existence of filaments. This applies especially to native metals. The cleavage is shown by the form of the fragments as in the case of galena, stibnite, carbonates, sphalerite, etc. The form of fracture, friability, etc., may also be observed.

2. *Their Transparence.*—With the exception of the metals, sulphides, and sulpho-salts, nearly all the minerals are somewhat transparent in the powdered form and the color is often diagnostic. In some cases, as in sphalerite, varying composition may be inferred by the variation in color.

3. *Their Optical Properties.*—Minerals such as wolframite, tantalite, and columbite, which are opaque in thin section, may be transparent and permit the determination of the pleochroism, birefringence, etc. The red minerals such as cinnabar, pyrargyrite, hematite, and cuprite, may be readily distinguished.

In the case of minerals giving a white streak the cleavage and optical properties usually serve to identify them. The fragments composing the streak may be submitted to tests with HCl, HNO_3, H_2SO_4, and other reagents. Often the products of the reaction are of more value than the reaction itself. It is stated that .00001 milligram of galena will give a characteristic test when treated with nitric acid. For minerals with a hardness of six or more, a quartz plate may be used to obtain the streak.

The advantages claimed for the method, and they seem well worthy of note, are: rapidity of examination, small amount of material used, material may be obtained from a crystal without damage, the determination may be quickly checked by comparing with the streak of known specimens, the tests are applicable to intricate mixtures.

The methods described would appear to be very useful in many cases and it is to be hoped that the details of the method will be forthcoming.

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SCIENTIFIC NOTES AND NEWS

H. G. Ferguson, of the U. S. Geological Survey, is in the Hawthorne quadrangle, Nevada, with headquarters in Mina. He is being assisted in the geologic mapping of this quadrangle by W. F. Foshag, of the U. S. National Museum.

Frank D. Adams, of McGill University, has resigned his position as dean of the faculty of applied science. He has been a member of the staff of the university for more than thirty-five years.

H. I. Jensen, formerly with the Queensland Geological Survey, has gone to Coorong, South Australia, to make a geological survey for the Central Coorong Oil Company of Melbourne.

A. C. Spencer is acting chief of the metalliferous section of the U. S. Geological Survey.

E. W. Todd, of the University of Toronto, is engaged in exploratory work for the Ontario Department of Mines.

W. B. Lang has resumed potash observations for the U. S. Geological Survey, with headquarters at Midland, Texas.

Robert Harvie, formerly of the Geological Survey of Canada, is now engaged in consulting work.

John Allen Fulton has been appointed director of the MacKay School of Mines, University of Nevada.

J. A. Bancroft, professor of geology at McGill University, is spending the summer at Anyox in an endeavor to extend the known limits of the Hidden Creek ore deposit.

F. L. Hess, of the U. S. Geological Survey, is investigating the occurrence of rare metals, including platinum and arsenic, in South Dakota, Wyoming, Colorado, Utah, Nevada, California, Arizona, and New Mexico.

G. I. Finlay, of the U. S. Geological Survey, is making oil investigations in the "Four Corners area," Utah, Arizona, New Mexico, and Colorado. He is assisted by Carle H. Dane.

James Latimer Bruce, formerly general manager of the Butte & Superior Mining Company and the Davis Daly Copper Company, has established offices in Salt Lake City as a consulting mining engineer.

K. F. Mather, of the U. S. Geological Survey, continued for a while the work of investigating the geologic conditions in the northeastern part of Colorado for the occurrence of oil, J. D. Sears having returned to Washington. James Gilluly and Ralph Lusk will remain in the field for the summer.

J. B. Tyrrell, vice-president of the Kirkland Lake Gold Mining Company, has also assumed the duties of Managing Director and Consulting Engineer to the company. The mine is located in the Kirkland Lake District of northern Ontario, Canada.

Adolph Knopf is making a geologic survey of the gold veins of the Mother Lode belt, California, for the U. S. Geological Survey. He is assisted by Thomas B. Nolan.

F. L. Finley and L. C. Gledhill are in charge of parties making investigations in the newer gold areas of Ontario, under the general direction of A. G. Burrows.

P. B. Dolman, formerly with the Carter Oil Company, has resigned to enter private practice. He is making a tour of the western and coastal oil fields before opening an office in Tulsa, Oklahoma.

A. J. Collier and C. D. Avery, of the U. S. Geological Survey, are in Rock Springs, Wyoming, working on anticlines in southern Wyoming.

E. C. Saint-Smith, formerly of the Geological Survey of Queensland, has accepted a position as manager of the Mt. Isa silver-lead mine.

E. Russell Lloyd is now engaging in practice as consulting geologist at 1104 First National Bank Building, Denver, Colorado.

John Wellington Finch has resumed practice as consulting geologist and engineer with offices at 301 High Street, Denver, Colorado.

C. Giburt Cullis gave a lecture before the Royal Society of Arts of London recently on the geology and mineral resources of Cyprus.

H. T. Stearns, of the U. S. Geological Survey, left Washington May 1 for Honolulu, where he will be engaged for several months on ground-water investigations in the Hawaiian Islands.

W. J. Mead, of the University of Wisconsin, delivered a series of three lectures on the rôle of colloids in metamorphic processes at the University of Chicago, May 15 to 17.

J. T. Pardee, of the U. S. Geological Survey, has returned from Florida, where he has been engaged in field work on the phosphate deposits of the State.

News has been received of the party for petroleum exploration in Alaska in letters from Philip S. Smith and J. B. Mertie, Jr., dated March 30, at a camp at the head of Unakserak River, near the Arctic divide. Mr. Smith had made a three day's trip across the divide and reached a stream in the Colville drainage basin. This survey furnishes the first definite information of the positions of the Colville drainage ways in this part of Alaska. Mertie and FitzGerald are to explore as far east as Chandalar Lake, and when the river opens, to survey the upper Colville, continue their survey across the portage to Chipp River, and follow that stream down to the Arctic Ocean. Smith and Lynt will make a winter exploration westward from the upper Colville and will later find a portage

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to the upper valley of Meade River and survey that stream until they make connection with the traverse run by Sidney Paige last year.

Joseph E. Pogue has a chapter on forecasting petroleum production in a book called "Problems of Business Forecasting," published by the Pollak Foundation for Economic Research.

Señor Rubio, Director of the Geological Survey of Spain and President of the Committee of Organization of the Fourteenth International Geological Congress, announces that on account principally of the conflict in dates between that previously set for the Geological Congress and that of the Geographical Congress to be held in Cairo in the Spring of 1925, the Spanish Government has concluded to postpone the meeting of the Fourteenth International Congress until the spring of 1926, at which time it will be entertained at Madrid.

The laying of the corner stone of the Newton R. Wilson Memorial Hall took place on the campus of Washington University on May 19.

At the Empire Mining and Metallurgical Congress held at London in June the following papers were presented to the section devoted to petroleum: Economics of the Oil Industry, by Sir Robert Waley-Cohen; Petroleum Geology, by T. Dewhurst; Petroleum Engineering: Drilling, by A. Beeby Thompson; Petroleum Engineering, by C. Dalley; Crude Oils of the Empire, by A. E. Dunstan and James Kewley; Refining of Oil Shale, by Edwin M. Bailey; Oil Transport: Tankers and Pipe Lines, by Herbert Barringer; Bulk Distribution of Oil: Depots and Bunkering, by Sir Frederick W. Black.

The British Association for the Advancement of Science will hold its annual meeting in Toronto, August 6–13. Some of the papers to be given under Section C, Geology, are the address by the President, Dr. W. W. Watts, professor of geology in the Imperial College of Science and Technology, London, dealing with economic geology, mining, and economic problems; The Upper Ordovician Section at Toronto, and The Dinosaurs of Alberta, by W. A. Parks; The Pleistocene of the Toronto Region, by A. P. Coleman; Gumbotil in Pleistocene Geology, G. F. Kay; The Direction of Cleat in Coal, by E. S. Moore; The Structural Features of the Kirkland Lake Gold District, A. Mac Lean; The Geological Features of the Keeley Mine, by J. M. Bell and Ellis Thompson; the Radioactive Minerals in Pre-Cambrian Formations, by Dr. Ellsworth; and discussion of other Pre-Cambrian problems by A. P. Coleman, T. T. Quirke, R. C. Wallace, and M. E. Wilson.